The use of social network analysis to study health care provider advice and performance

Kate Sabot

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I, Kate Sabot confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Kate Sabot

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Abstract

Introduction: Social network analysis quantifies and visualises communication pathways between actors. This thesis focuses on the application of social network analysis methods to explore healthcare worker professional communication and performance by conducting a systematic review and a network study in Ethiopia.

Paper 1: The systematic review analysed what social network methods have been used to study professional communication and performance among healthcare providers**.** Ten databases were searched from 1990 through April 2016, yielding 5,970 articles. There was marked diversity across all six studies meeting our search criteria in terms of research questions, health sector area, patient outcomes and network analysis methods. The paucity of articles, the complete lack of studies in low and middle-income contexts, the limited number in non-tertiary settings and few longitudinal, experimental designs or network interventions present clear research gaps.

Paper 2: A cross-sectional, mixed-methods observational network study captured professional advice networks of 160 healthcare workers in eight primary health care units across four regions of Ethiopia. Data included health care worker advice seeking and giving for the provision of antenatal care, childbirth care, postnatal care and newborn care. Adjacency matrices were uploaded into UCINET 6.0 to calculate network metrics. Networks were visualised using NetDraw. Qualitative interviews of 20 purposively selected subjects followed the collection of quantitative network data to interpret and explain network roles and patterns observed. Expanded field notes were analysed using MaxQDA10. Results: Informal, inter-and intra-cadre advice networks existed. Fellow staff were preferred, but not limited to the primary health care unit. Average network-level metrics: density .26 (SD.11), degree centrality .45 (SD.08), distance 1.94 (SD.26), ties 95.63 (SD 35.46), network size 20.25 (SD 3.65).

Conclusion: The systematic review found that network methods are underutilised in this area. The subsequent network study in Ethiopia serves to provide foundational information on healthcare worker professional advice networks.

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Since starting my doctoral degree in 2011 I have had three babies, Quillan in 2013, Luka in 2016 and now this “DrPH baby” with an estimated due date in 2018. Optimal spacing! Thank you to my husband, Oliver for your willingness to embark on adventures in single parenting during my periodic absences. For when mommy is away inevitably norovirus strikes or a major power surge destroys all electronics in the house. Oliver, thank you for your sense of humour, love and support. You’ve helped me weather the emotional highs and lows that invariably come with a doctoral degree and stay optimistic and focused. This document is a testament to your belief in me and willingness to travel with me around the world.

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List of Abbreviations

ADE	Adverse Drug Event
AG	Advice Giving
ANC	Antenatal Care
AR-BSI	Access-Related Bloodstream Infection
AS	Advice Seeking
BEmONC	Basic Emergency Obstetric & Newborn Care
BSI	Bloodstream Infection
CASP	Critical Appraisal Skills Programme
CDC	Centers for Disease Control and Prevention
CBNC	Community-based Newborn Care
CHP	Community Health Promoter
CMAM	Community Management of Acute Malnutrition
CNA	Certified Nursing Assistant
COREQ	Consolidated Criteria for Reporting Qualitative Research
CSTWG	Child Survival Technical Working Group
DOI	Digital Objective Identifier
ED	Emergency Department
ENAP	Every Newborn Action Plan
ENTREQ	Enhancing Transparency in Reporting the Synthesis of Qualitative Research
EPOC	Effective Practise and Organisation of Care
FANC	Focused Antenatal Care
FGD	Focus Group Discussion
FMOH	[Ethiopian] Federal Ministry of Health
GLMM	Generalised Linear Mixed Model
HC	Health Centre
HCW	Health Care Worker
HDA	Health Development Army
HEP	Health Extension Programme
HEW	Health Extension Worker
HMIS	Health Management Information Systems
HO	Health officer
HP	Health Post
HSDP	Health Sector Development Plan
iCCM	Integrated Community Case Management
ICU	Intensive Care Unit
IDEAS	Informed Decision for Action
IMNCI	Integrated Management of newborn and childhood illness
IRB	Institutional Review Board
IT	Information Technology
ITS	Information Technology Sophistication
LMIC	Low and middle-income country
LPN	Licensed Practical Nurse
MA	Medical Assistant
MAT	Maternity
MDG	Millennium Development Goal
MLE	Measurement, Learning and Evaluation

MMR	Maternal Mortality Ratio
MNH	Maternal and Newborn Health
MW	Midwife
NCD	Non-communicable disease
NEW	Newborn Care
NH	Nursing Home
NS	Nurse
NHAMCS	National Hospital Ambulatory Medical Care Survey
OPA	Organisational and Policy Analysis
ORA	Organisation Risk Analyser
PHCU	Primary Health Care Unit
PNC	Postnatal care
PPH	Post-Partum Haemorrhage
PRCMM	Performance Review and Clinical Mentoring Meeting
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
QARI	Qualitative Assessment and Review Instrument
RATS	Relevance of study question, Appropriateness of qualitative methods, Transparency of procedures and Soundness of interpretive approach
RN	Registered Nurse
SDG	Sustainable Development Goal
SIGN	Scottish Intercollegiate Guidelines Network
SNA	Social Network Analysis
SNNP(R)	Southern National Nationalities Peoples (Region)
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
TFP	Therapeutic Food Programme
ToT	Training of trainers
vCHW	Volunteer Community Health Worker
WDT	Women's Development Team

1 Integrating Statement

I started my DrPH in 2011 after 5 years of working in monitoring and evaluation for a non-profit organisation both in Tanzania and as part of a global team supporting 33 countries. I was drawn to the DrPH program rather than a traditional PhD as I desired practical training in leadership and management as well as development of my research skills. I envision continuing my career working in the field and do not see myself as only conducting academic research. I intend to lead measurement, evaluation and learning activities for NGOs, public health institutions, working with and for governments. As I hope to be in roles shaping organisational structures, training in management theory was very important to me. The most effective leaders I interacted with had management training. Having a more comprehensive understanding of management theory would allow me to be more conscious in my future management roles. Further down my career trajectory I would like to focus on training the next generation of public health professionals. As such expanding my teaching experience was another reason I chose to pursue doctoral training. In particular, LSHTM's experience as a leading distance learning institution appealed as I see the distance learning program as a way to extend high quality training to places in the world where such calibre institutions have yet to be built. In sum, my DrPH program goals were to 1) improve my research skills, 2) gain an understanding of management theory and practice and 3) build my teaching experience and skills. This statement provides an overview of how I achieved these goals through the three components of the DrPH Programme: the taught component, the Organisational and Policy Analysis (OPA), and the research thesis.

The taught component of the DrPH program provided valuable time and direction to engage in management and organisational theory as well as further my understanding of how to generate and use evidence to influence decision making, policy development and ultimately, public health practice. The assessments involved synthesising information for a systematic review and designing an influencing and knowledge transfer strategy to get a research-driven issue on the policy agenda of a Ministry of Health. The Leadership, Management and Professional Development module introduced me to management and organisational behaviour theory. It also provided an opportunity to better understand how my personality influences my leadership style. I was also able to understand the implications for management and organisational structures in which I plan to thrive. The module assessment involved selecting an organisation and conducting a "mini OPA". I selected the International Initiative for Impact Evaluation (3ie) a young organisation focused on evidence generation, synthesis and use. I then conducted a desk review of publicly available documents to assess 3ie's planned organisational response to achieve greater policy impact and provide recommendations grounded in relevant organisational and management theories. Through this I applied several analytical tools: PEST

analysis (Political, Economic, Social and Technological), SWOT analysis (Strength, Weaknesses, Opportunities and Threats), 7-S Framework (Strategy, Structure, Systems, Shared Values, Skills, Style and Staff) and Kotter's 8 stages of change.

Building upon the management theory explored during the Leadership, Management and Professional Development course, I used the Organisational and Policy Analysis (OPA) project as an opportunity to conduct a management study. The overall purpose of an OPA is to understand how public health organisations function to influence public health policy and/or deliver public health goals. In this case my host organisation, Sambodhi Research & Communications Pvt Ltd., was a private company founded in Delhi, India in 2005 providing evaluation and research consulting services. Sambodhi's thematic areas span a wide range of development topics including health. Sambodhi had experienced dramatic growth over the previous six years as evidenced by the breadth of their clientele, their expansion into training of M&E professionals and their intention to establish a Research & Management Institute. The aim of my OPA was to provide a critical analysis of Sambodhi's organisational model, management style and institutional culture over the course of 3 months of fieldwork, being embedded within the company. Sambodhi is the kind of company I could see myself starting or working for in the future. As such understanding how to best navigate the transition from the high growth of a start-up to sustainable institutional development is a critical issue for any new company. For this reason, in combination with it being my first time working with the private sector, designing and conducting this management study was an insightful experience. I then wrote a 12,000-word academic report summarising this research project.[1]

While in India for my OPA, I began exploring teaching opportunities. I was a guest lecturer for the Public Health Foundation of India, a preeminent public health institute in India. I prepared lectures on logic models and real-world applications of M&E theories and tools for a public health nutrition programme's M&E module. Back at LSHTM I continued to expand my teaching skills and experience. I look two courses on adult learning and providing students feedback. I then served as a tutor for IDM101: Principles of Biostatistics and Epidemiology, ITD3196: Analysis and Design of Research Studies, IDM104: Control of Infectious Diseases, IDM3195: Epidemiology and Control of Malaria, and EPM201: Grant Proposal Development. My responsibilities varied from grading exams, writing exam questions and marking guides, to moderating online question and answer forums. I also was a guest lecturer for Evaluation of Public Health Interventions.

[1] As part of my agreement with Sambodhi, the report and results from the management study were to be kept confidential, with only my supervisor and the assignment examiners privy to the contents. As such, I am not at liberty to expand in describing the results here.

Teaching has provided a nice complement to my research work. It has also provided a refresher on epidemiological concepts that I do not use on a daily basis. Once I completed and passed both the compulsory modules and the OPA, I prepared for my DrPH review. This is the equivalent to an upgrade for PhD students. This allowed me to present my thesis research plan to two LSHTM staff not affiliated with my project to assess its academic rigor.

My DrPH thesis is built upon work I led as a research fellow for Informed Decisions for Action (IDEAS), a research group, which aims to improve the health and survival of mothers and babies in India, Nigeria and Ethiopia through generating evidence to inform policy and practice. My thesis focused on the application of Social Network Analysis (SNA) methodology to explore healthcare worker professional communication and performance through conducting a systematic review and a network study in Ethiopia. For the systematic review I designed the protocol and managed the search and analysis from start to finish. The systematic review was published in *Systematic Reviews*. It synthesised the existing literature using SNA methods to understand the relationship between professional advice networks and performance. I now feel well equipped to oversee the direction and execution of future systematic reviews as needed. The subsequent network study of health professional advice networks in Ethiopia used mixed methods. I taught myself SNA methods, through reviewing classic texts and literature, taking a coursera course and attending the Sunbelt conference, the annual gathering of network analysts. I prepared the study protocol, consulted with experts, developed tools through conducting iterative field testing, obtained ethical approval at LSHTM and within Ethiopia, developed field guides training materials and trained enumerators, remotely supervised data collection, entered and analysed the data. I am the lead author on the initial paper emerging from this body of work.

The Ethiopia network study provided foundational information on healthcare worker professional advice networks in Ethiopia. Network scientists will value this study as it pushed the frontiers methodologically and geographically as both quantitative and qualitative network methods were applied to a primary health care setting in Africa. It is relevant to health researchers and policy makers in Ethiopia or other low and middle-income countries who may consider use of professional advice networks to improve the implementation of health programmes.

The most powerful learning experiences over the course of my doctoral training has come from failures. The performance data collected alongside the quantitative SNA survey was inconsistent. Conducting analyses linking network properties to performance would have at best been an academic exercise and at worst irresponsible-- misguiding policy makers. I have consoled myself that if this were easy, all SNA studies would capture performance data and that

this was a context with more complicated data quality issues than most SNA study contexts. During qualitative data collection, poor connectivity impeded my ability to provide real-time feedback to the interviewers. Consequently, there were limitations in what could be learned from the first five interviews.

While learning from failures, this body of research offers a valuable academic contribution with potential policy implications. The SNA study is the first network study of primary health care providers' professional advice networks in Ethiopia and the findings are relevant to a range of audiences as described above.

I am grateful for the opportunities and guidance afforded to me at LSHTM through the DrPH programme, the IDEAS research team, my supervisor and committee. My three goals were achieved, and more importantly, my perspective towards these goals shifted. The DrPH is not an end to improving my research, management and teaching skills, but a new beginning. My DrPH has been an important step in the process of continuous learning and growth that I hope will define my career.

2 Introduction

2.1 Thesis Structure

This document is structured around two papers: a systematic review and a network study. The thesis document starts with an overall abstract. The DrPH Integrating statement follows, a document that explains how the different components of the DrPH relate to each other and explains why the thesis is shorter than a traditional PhD. Subsequent sections include a general introduction, a brief overview of the aims and methods, followed by the two papers, then a brief results, discussion and conclusion. The introduction, methods, results, discussion and conclusion serve to complement the material covered in the papers. To limit repetition, these sections often refer to the content of the two papers. Where it would be disruptive to reference other sections, the content is repeated for flow purposes. Annex 1 contains all of the additional files for paper 1. Annexes 2-12 contain supplemental information about the Ethiopian Network study. Annex 13 contains the additional files for Paper 2.

References are grouped in 4 locations. The first set of references cover those found in the Introduction up until the first paper. Each paper has its own set of references. The last set of references are those from the end of the second paper through to the Annexes. Annex 1 references are numbered according to those for Paper 1. The rest of the annexes where references are not listed immediately within the annex are associated with those found in Paper 2.

This Introduction serves two purposes: 1) review basic background information on relevant Ethiopian health statistics, the health system and delivery structure and how that has evolved and 2) introduce social network analysis concepts, methods and applications in the health sector, in Ethiopia and in professional advice networks.

2.2 Ethiopia background

Ethiopia is a landlocked country in the horn of Africa surrounded by Kenya, Somalia, Eritrea, Djibouti, Sudan and South Sudan. 2017 projections estimate 105 million people live in Ethiopia, making this the 12th most populous country [91].[2] Administratively, Ethiopia is divided into 9 regions (plus 2 administrative cities), 85 zones, 817 woredas, and 16,253 kebeles [1]. Four of the regions are referred to as the Agrarian regions: Oromia, Amhara, Tigray and Southern Nations, Nationalities and Peoples (SNNP) region. Collectively, these four regions are home to over 80%

[2] These estimates are based on projections from the 2007 census data. The Ethiopian Central Statistics Agency conducted a census in 2017, therefore updated statistics are expected.

of the Ethiopian population [91]. Some of the variability linguistically, culturally, economically, administratively across these regions are described in the Table below.

Table 1: Ethiopia Regional Descriptions

Region	Summary
Oromia	Oromia is home to approximately 32 million people, or 37% of the overall Ethiopian population [91]. It covers 353, 690 square kilometres (approximately 32% of the physical geography of Ethiopia) and borders Kenya, Sudan and the following Ethiopian states: Afar, Amhara, Somali, Benishangul Gumuz, SNNP and Gambella [91]. Approximately 90% of the population are small-scale subsistence farmers, and the main cash crop is coffee [91]. There is limited ethnic diversity with 85% of people in Oromia of Oromo descent [91]. The language of the Oromo people is Oromifa, less than 2 percent speak a language other than Oromifa, Amharic or Tigrinia [91]. The capital city of Oromia is Addis Ababa. The health system follows the standard regional, zonal, woreda, and PHCU structure common in most of Ethiopia.
Amhara	Amhara is home to approximately 19 million people or 22% of the Ethiopian population [91]. 90% live in rural areas, 10% in urban [91]. It covers 170,752 square kilometres [91]. 85% of the region are farmers producing most of the country's Teff (the grain indigenous to Ethiopia and the basis of injera, a local staple food) and other grains [91]. The language of Amhara is Amharic, the language most commonly associated with Ethiopia and the national language. Ethnic diversity is limited with over 90% of Amhara descent [91]. The regional headquarters is in Bahir Dar. The health system follows the standard regional, zonal, woreda, and PHCU structure common in most of Ethiopia.
Tigray	Tigray is home to approximately 5 million people, or 6% of the Ethiopian population [91]. It covers 80,000 square kilometres located in the northern most part of the country and borders Eritrea, Sudan and the following Ethiopian states: Afar, and Amhara [91]. 83% of the region are farmers with Teff, wheat and barley the primary crops [91]. The language of Tigray is Tigrinia. Tigray is home to many iconic cultural sites. Ethnic diversity is limited within Tigray with 95% of Tirgrinia descent [91]. The health system officially follows the standard regional, zonal, woreda, and PHCU structure common in most of Ethiopia, however with limited zones this level is less meaningful than

	in other regions. However, PHCUs and the HEP remain structured the same as in the rest of the Agrarian regions.
SNNP	SNNP is home to approximately 18 million people, or 21% of Ethiopia's population [91]. 93.2% live in rural areas [91]. It covers 112,323 square kilometres, bordering Kenya in the south, Sudan, Oromia and Gambella Regions [91]. Over 90% of the region are farmers with coffee being the most prominent crop [91]. As a region made up of many ethnic groups there is not one regional language, and Amharic serves as the official working language. Ethnic diversity is pronounced with over 45 different ethnic groups [91]. The health system officially follows the standard regional, zonal, woreda, and PHCU structure common in most of Ethiopia.

2.3 Ethiopia Health Statistics

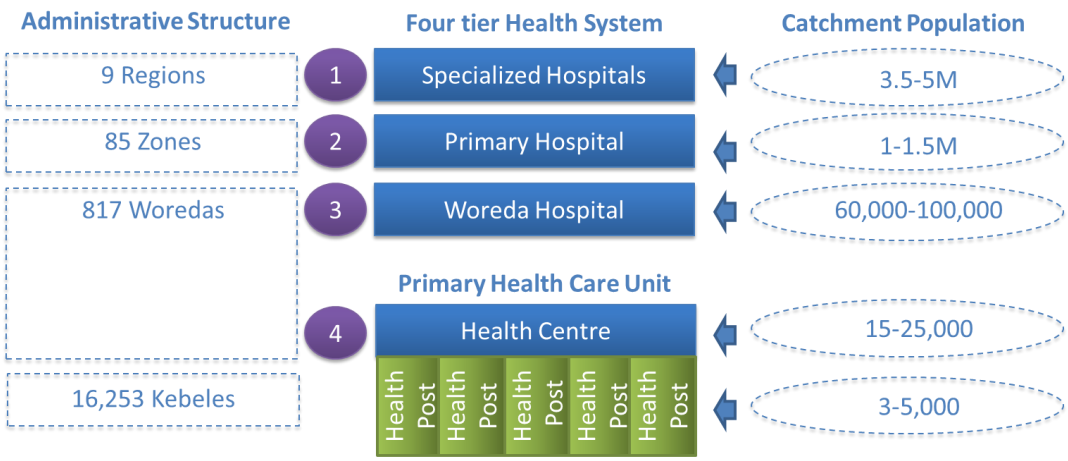
Clear progress has been made in addressing child (under 5) mortality, with achievement of the associated MDG met three years early. Neonatal and maternal mortality stagnated, although the most recent DHS indicated improvements [89]. In 2011, only 19% of pregnant women attended at least 4 ANC visits, in 2016 that increased to 32% [2,89]. Facility delivery increased over the same period from 10% to 26% [2,89]. Similarly, for PNC in 2001 7% had a PNC visit within 48 hours of birth and by 2016 that increased to 17% [2,89]. This section primarily focuses on neonatal mortality as the network study was implemented in areas where a programme to address newborn care was introduced.

Neonatal deaths account for approximately 42% of under 5 deaths [2]. According to the Ethiopian government, major causes of neonatal mortality are preterm birth (17%), asphyxia or intrapartum related deaths (25%), and infection (36%) [3]. A recent study of the past three demographic health surveys in Ethiopia (2000, 2005, 2011) found the following statistically significant negative associations with neonatal mortality: neonate male gender, maternal age less than 18, neonates born within two years of preceding birth, winter births. The studies also identified the following statistically significant protective associations: maternal education, maternal receipt of two doses of tetanus toxoid prior to birth [4]. The Ethiopian Health Sector Development Plan IV (2010-2015), indicates that maternal and newborn health is a priority [5]. The Ethiopian Health Sector Development Programme is a series of four consecutive five-year plans which started in 2001/2002[5]. The HSDP the guiding long-term framework for the health sector to develop capacity to deliver health services.

2.4 Healthcare delivery context in Ethiopia

The second paper provides an overview of the Ethiopian health delivery context. The graphic below was not part of the paper, but gives a helpful overview of the health system.

Figure 1: Ethiopian Health System Structure



Additional background information on the Health Extension Programme is expanded upon here to complement what appears in the second paper.

2.4.1 The Health Extension Programme

The Ethiopian health extension programme (HEP) has been heralded as one of the great innovations in delivering community-based healthcare at scale. The HEP was introduced under Phase two of the Health Sector Development Programme in 2003, patterned after the Agricultural Extension Programme as the primary vehicle for reaching the Millennium Development Goals. The HEP became operational in 2005 with a goal of introducing 30,000 Health Extension Workers (HEWs) in 15,000 health posts. HEW are envisioned to be the link to the community, spending approximately 25% of their time at the health post and 75% in their communities [6, 7]. Over the past ten years, as programme coverage increased well beyond the initial targets, so too, have the volume of services to be delivered via the HEP platform. Please see Figure 2 below for a timeline of the HEP development. The HEP has three versions—Agrarian, Pastoralist and Urban—to meet the unique needs of Ethiopia's rural, nomadic and urban communities. The relative proportions of the HEP versions (see Figure 2) reflect the distribution of people living in Ethiopia more broadly, with over 80% of the population living in the 4 Agrarian regions. The differences across the three versions of the HEP are described below.

2.4.1.1 Agrarian Health Extension Programme

The Agrarian HEP represents the first version and the bulk of the HEP (approximately 89%, see Figure 2), as it is operational in the most populous regions in Ethiopia—Amhara, Oromiya, Tigray

and the Southern National Nationalities Peoples Region (SNNP). Most of the published literature relates to this version of the HEP, and it is often not specified as “Agrarian”. The Agrarian HEP was piloted in 2003 and became fully operational in 2005 with HEW trained to deliver a set of 16 essential health services including both preventive and curative services spanning 4 major areas of care. They are family health, disease prevention and control, hygiene and environmental sanitation, and health education and communication [7].

2.4.1.2 Pastoralist Health Extension Programme

The Pastoralist HEP was introduced in 2006 in Afar, Somali, Benishangul, Gumuz, and Gambella regions, with the main distinction from the Agrarian HEP being men serving as HEWs [8]. The Pastoralist HEP represents approximately 2% of the overall HEP (see Figure 2).The programme has been criticised for not tailoring more to the needs of pastoralist communities, particularly around health and hygiene issues unique to mobile populations [9].

2.4.1.3 Urban Health Extension Programme

The urban HEP was launched in Addis Ababa, Dire Dawa, and Harari urban areas in 2012. As of 2014 there were 3,401 urban HEWs [10], representing approximately 9% of the HEP (see Figure 2) In this version of the HEW programme there are 15 services grouped under 4 themes: Environmental Hygiene, Family Health services, Disease prevention and accident and injury prevention. The focus on chronic disease prevention and environmental health intends to address issues more relevant to those in urban areas [11]. The most meaningful change is the introduction of accident and injury prevention and that the HEWs are trained nurses [10].

2.4.1.4 Health Extension Programme Scope Evolution

Since its inception in 2003 and operationalisation in 2005, the HEP has evolved, with the addition of services to be provided through the programme platform. In 2008 community management of acute malnutrition (CMAM) and the therapeutic food programme (TFP) were added [12]. In 2010 integrated community case management (iCCM) of childhood illnesses, noncommunicable diseases (NCDs), Mental Health and Emergency Care were added [13]. In 2010 the family folder was added as a tool to assist HEWs in tracking services provided to family units and monitor their progress towards being model households [14]. In 2011 treatment of pneumonia was added [15]. In 2012 Basic Emergency Obstetric & Newborn Care (BEmONC) was introduced as a service provided at health centres [16]. The most recent change occurred in 2014 with the launch of community-based newborn care (CBNC). CBNC introduces community-based management of sepsis and active identification of pregnant women, and new mothers and babies for engagement in the health sector [17].

2.4.1.5 Community-based Volunteer Support

The HEP does not operate in a vacuum, there are other Ethiopian institutions that interact and serve to support implementation. Community volunteer cadres, have evolved over the course of the HEP's lifespan. Prior to 2010 the community health workers, referred to as Community Health Promoters were replaced by the Health Development Army [18]. This new cadre represented a restructuring of community workers around the "model house" concept. Model households are homes that have been determined to have met a set of criteria around hygiene and health standards. One in every five households is intended to be a "model house" and lead a "1-5 group." Groups of five to six of these "1-5 groups"—approximately thirty households—form a "1-30 group" or development team and are led by the development team leader. The 1-5 and 1-30 groups help connect communities to the healthcare system and their leaders train and support "model families" to adopt preventative health measures [30]. These women support Health Extension Workers in identifying pregnant women and encouraging them to go to the health posts for antenatal care and other maternal and child health services. On a regular basis the leaders of the 1:5 and 1:30 groups meet with the Health Extension Workers in their kebele to review relevant health topics. This cadres' mandate extends beyond health and they also report to the command post, the governing body within the kebeles. Recently the Health Development Army cadre has been renamed the Women's Health Development Team, although it is more commonly referred to as the women's development team [19]. Approximately 20 of the 1:30 women's development team leaders support each HEW.

2.4.1.6 Infrastructure Developments

The Primary Health Care unit (PHCU), comprised of one health centre and approximately 5 health posts. Health Centres are staffed by nurses, midwives and usually one or two health officers whereas health posts are staffed exclusively by HEW. PHCUs are supported by woreda, zonal and regional bodies (in regions where all of these levels exist) for regular supervision and training.

Health posts were introduced as part of the HEP. Figure 2 charts the construction of health posts to the original goal of 15,000 and beyond. Health Centres have similarly increased, and their progress is included in Figure 2.

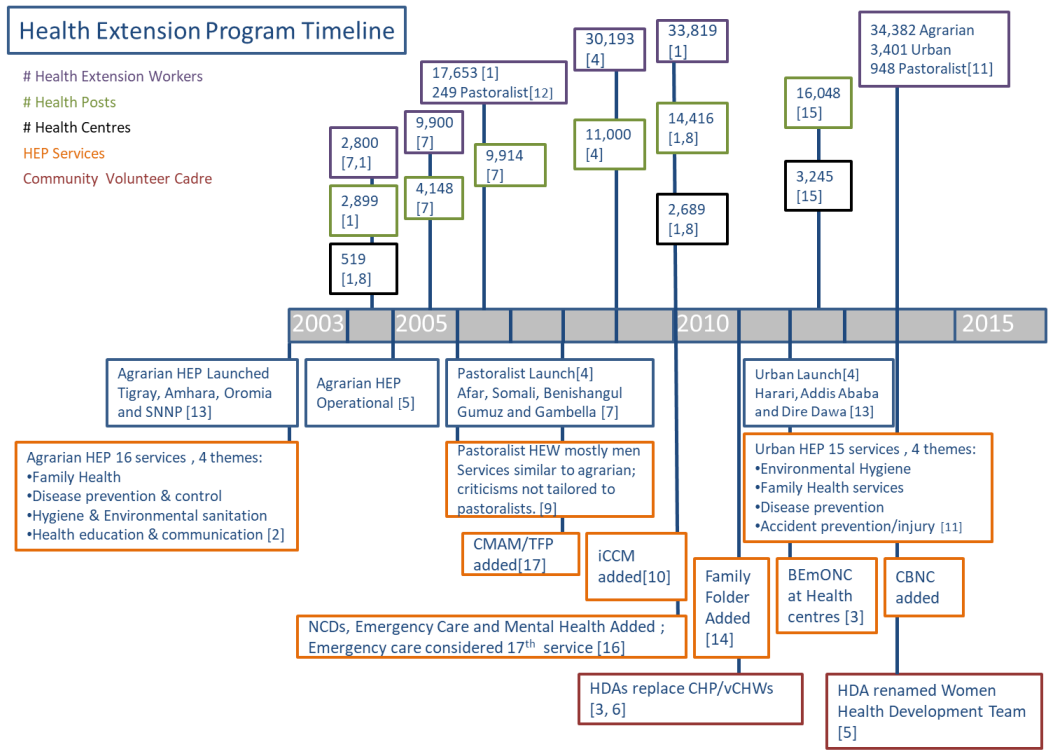
2.4.1.7 Achievements of the Health Extension Programme

The HEP was conceived in 2002, became operational in 2005 and exceeded its human resource and infrastructural targets in 2012. Ethiopia's successes in delivering primary healthcare as evidenced by achieving its child mortality millennium development goal three years ahead of

schedule may be attributable in large part to the roll out of the HEP. The HSDP III described the HEP as the most important institutional framework for achieving the MDGs [20].

Studies of HEWs have found their potential to yet be fully realised, calling for additional training and resources [7, 21-23]. Further tailoring of the urban and pastoralist HEP are needed to meet the unique needs of their target populations [24]. A multi-country comparison of community health worker programme supply chain management found 9% of HEW trained in supply chain management, 13% maintaining stock records and only 4% in possession of SOPs. The supply chain management burden on CHW in Ethiopia was much higher than comparison countries with HEW managing approximately 50 products whereas in Malawi they managed 19 and in Rwanda 5-8 [15]. Programme critics have pointed to limitations in HEW training that prevent them from being able to address many of the health problems they face.

Figure 2: Timeline for Health Extension Programme Developments in Ethiopia 2003-2015 [1, 5, 7-9, 12-14, 16, 18-20, 24-29]



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2.5 Community-based Newborn Care Overview

CBNC is a new maternal and newborn health programme building on the HEP platform. A recent review reported that 71% of neonatal deaths can be prevented through improved coverage of a few key interventions [31]. CBNC aims to address these via the "4 Cs" and "9 Components" listed below.

9 Components of CBNC

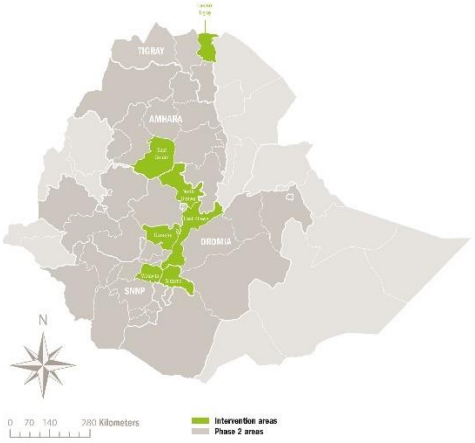
1. Early identification of pregnancy
2. Provision of Focused Antenatal Care[3]
3. Promotion of institutional delivery
4. Safe and clean delivery; misoprostol
5. Immediate newborn care; Chlorhexidine cord care
6. Recognition of asphyxia, stimulation and resuscitation
7. Prevention and management of hypothermia
8. Management of pre-term and low birth weight
9. Management of neonatal sepsis at community level [17]

And the "4 'C's"

1. **Contact** with mother and newborn
2. **Case identification** of newborn
3. **Care or treatment** of newborn
4. **Completion** of 7-day antibiotic course

[3] Focused Antenatal Care (FANC) has 8 components 1) Four ANC visits 2) Counselling on birth preparedness 3) HIV counselling and testing 4) Counselling for family planning and nutrition 5) STI diagnosis and treatment 6) Two doses of Tetanus toxoid 7) Iron/Folate supplementation and 8) Detection and management of complications [17].

Figure 3: CBNC Phased Implementation Zones for Network Study PHCU Selection [90]



What sets this programme apart from previous community-based efforts in Ethiopia is the active case detection and follow-up by the community-based health workers. Additionally, this programme introduces community-based management of sepsis.

CBNC was introduced in three phases through cascading trainings and supported by routine supervision (see Figure 3). Phase I (green areas in Figure 3) began in 2014 in seven zones within four regions, chosen for their diversity and population density. Phase II (dark grey areas in Figure 3) started in January 2015 and Phase III expanded CBNC into the Pastoralist regions (light grey areas in Figure 3).

Informed Decision for Action (IDEAS) was requested by the Ethiopian Federal Ministry of Health (FMOH) to support an overall evaluation of the CBNC Phase I Programme. IDEAS in partnership with an Ethiopian measurement and learning partner, JaRco Consulting, Ltd. collected baseline (October 2013), midline (November 2015) and endline data (November 2017) from health centres, health posts, healthcare workers and households in a mixed methods design.

2.6 Introduction to Social Network Analysis

The literature presented below includes background on social network analysis, SNA studies in health and SNA studies in Ethiopia. Comprehensive overviews of SNA already exist [32, 33], this review focuses on what is most relevant to the study. In particular, the review focuses on what is known about the association between SNA metrics and other network properties and performance.

2.6.1 Social Network Analysis Basics

2.6.1.1. What is a social network?

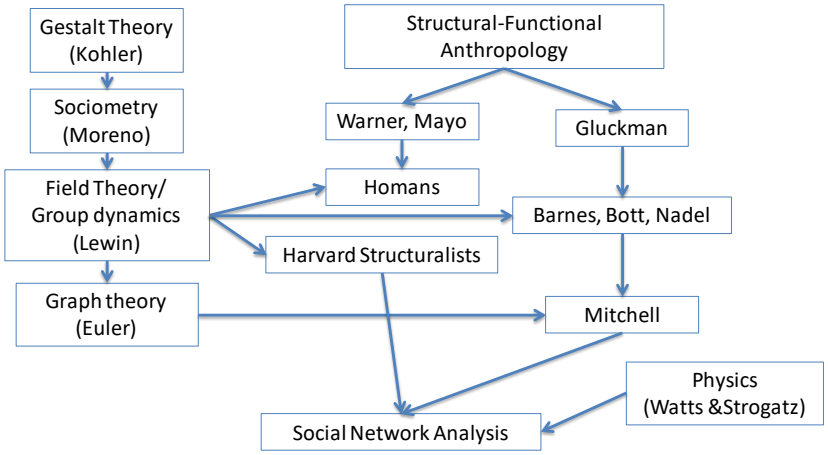
A social network is a set of socially relevant nodes, representing either individuals or organisations, connected by one or more relations [88]. The lines between the nodes are referred to as either ties or relations and reflect the relationship of interest.

"Social network analysis (SNA) offers a means of mapping and exposing the hidden channels of communication and information flow, collaboration and disconnects between people" [34]. It is a structuralist paradigm: "it conceptualises social life in terms of structures of relationships among actors, rather than in terms of categories of actors as a paradigm it is composed of a theory or theories, a methodology or set of commonly employed methods, and a body of empirical research" [35].

2.6.1.2 A brief history of Social Network Analysis

SNA's non-linear development with concurrent developments in a wide range of fields is reflected in the variety of pathways described. Scott's lineage outlines the following trajectory with three main traditions 1) the sociometric analysts, 2) the researchers of the 1930s looking at interpersonal relations and 3) the social anthropologists looking at community structures leading to the forging of modern social network analysis in the 1960s and 70s [36]:

Figure 4: Social Network Analysis Lineage



Social network analysis is inherently interdisciplinary with anthropology, agriculture, sociology, psychology, communication, economics, organisational behaviour, knowledge management, marketing, social psychology, public health, medicine, computer science, policy, counter terrorism fields, among others engaged in the paradigm. As demand has grown for SNA, so too, has the learning community with multiple professional associations, annual conferences, journals, training opportunities and a plethora of bespoke and generic software packages for use in SNA.

2.6.1.3 Social Network Analysis Theoretical Frameworks

There are six core theoretical frameworks that have been developed or applied to guide SNA studies: social capital, network exchange/social exchange, biased net theory, social influences, social selection network theory and diffusion of innovations [37].

The systematic review uses the term “diffusion of innovations”, a theory that looks at how an innovation is communicated through social networks to identify articles about knowledge sharing. The SNA study is not focusing on how a single innovation travels through a network, but rather looks at advice exchange within the network.

There are varying theoretical foundations for understanding the roots of professional advice seeking and giving within organisations. According to Agneessens, the social exchange framework has two slightly competing theories- social status and social capital. Social status argues that advice giving generates prestige and advice asking decreases standing, whereas with social capital advice is seen as a currency with giving generating a future obligation and seeking incurring a debt. These theories have network implications, as you would expect non-reciprocal dyads and non-cyclical triadic structures if social status is the motivation, and you would expect more reciprocity if social capital is the foundation of advice networks [38]. Alternatively, social influences theory can be applied to understand and hypothesise around professional advice communication. Social influences theory looks at how actors influence each other’s’ thought processes and behaviours. While each of these theories offer compelling rationales for advice seeking and giving, within the context of professional advice seeking and giving among PHCU health care workers I assume motivations for such communication are more nuanced and reflect a combination of these motivations depending on the individuals involved and the specific exchange. This study will seek to explore that further and test these theories in the Ethiopian context.

2.6.1.4 Network study design considerations

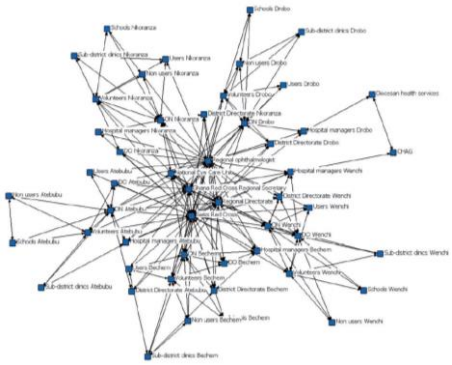
The main approaches to SNA study either whole networks or ego networks, involving sampling and capturing the networks of individuals rather than the whole network. Whole network studies seek to measure the structure of some bounded social group by collecting data on a relationship that links the actors within the group [35]. Hybrid models combine elements of both approaches. There are two main approaches to boundary specification—nominalist and realist. A realist approach allows study participants to define their own network whereas a nominalist approach uses a formal criteria to determine the network [86]. All networks are characterised by mode, whether the network is directed or undirected, valued or dichotomous [87]. “Directed” networks have arrows attached to the lines connecting actors, showing if the relationship is reciprocal between actors or from one actor towards another. “Valued” network relations have a scaled weight, representing a characteristic such as frequency or strength of relationship. There are several levels at which SNA data can be analysed: actor, subgroup or complete network [87]. SNA data are captured through questionnaires, interviews,

observations, existing records, diaries or other methods [87]. Most—although increasingly, not all— SNA studies are cross-sectional, representing a single point in time.

2.6.1.5 Visual representations of Social Networks

Social network diagrams, or digraphs, are a particularly useful means of exploring and representing SNA data as they allow for communicating information in context and can display a range of relationships simultaneously [39]. In SNA visualising data is both a means of presenting findings as well as a tool for exploring SNA data to identify patterns and generate findings. The most basic SNA diagrams depict nodes as points with connecting lines. It is possible to overlay additional information about the actors or relationships. These attributes can be displayed by changing the colour, size or shape of the actor. Valued networks can be represented by adjusting the thickness of lines connecting nodes according to the strength of the relation. There are general guidelines about the production of visualisations generated using SNA software packages which emphasize effectiveness, efficiency and readability [39].

Figure 5: Example of Social Network Visualization [16]



These visualisations can reveal information about patterns of relationships between the nodes like identifying subgroup structures clusters, presence of brokers (gatekeepers), core-periphery structure and the presence of isolates.

Diagrams, also called graphs are one of two tools SNA borrows from mathematics, the other being matrices/matrix algebra [40]. A matrix is a simple table with nodes listed both horizontally and vertically to capture the relationship between each node and every other node in the network. If the data captured are valued, those values appear in the matrix. See below for examples.

Table 2:One-mode adjacency Matrix

	n_1	n_2	n_3	n_4	n_5	n_6	n_7
n_1	-	1	0	0	1	1	0
n_2	1	-	1	1	0	0	1
n_3	0	0	-	0	1	0	0
n_4	1	0	1	-	1	1	1
n_5	1	1	1	0	-	0	0
n_6	1	0	1	1	1	-	0
n_7	0	1	0	1	1	0	-

Table 3:One-mode valued adjacency Matrix

	n_1	n_2	n_3	n_4	n_5	n_6	n_7
n_1	-	1	2	5	3	1	3
n_2	1	-	1	2	1	1	1
n_3	1	1	-	2	1	4	1
n_4	5	2	2	-	2	2	1
n_5	3	1	1	2	-	1	1
n_6	1	1	4	2	1	-	5
n_7	1	1	1	2	1	5	-

2.6.1.6 Network Metrics

While both papers describe social network analysis metrics, key metrics are summarised here. For more information please see Annex 1 Additional File 2 for Paper 2. Standard SNA metrics typically calculated in SNA health systems research studies are given below [70]. Some of these can be calculated at the sub group or actor level, as noted in the table below.

Table 4: SNA Metrics for Health Systems Research Definitions and Usage

SNA Metric	Level	Definition	Comments on Use
Density	Network/ subgroup	Existing ties divided by the number of possible ties	Assesses cohesion in combination with other metrics. Sensitive to variations in network size.
Centrality	Actor/Network	*Degree centrality:* Number of immediate contacts a node has in a network; eigenvector centrality (expands and weights according to an actor's centrality); in-degree and out-degree centrality relate to the direction of the nominations.[37]	Central actors and centralised networks can quickly interact with all members.[87] Network measure useful for identifying core-periphery structures.[37] Not useful for comparing networks unless identical in size.
	Actor	*Betweeness Centrality:* Captures frequency of an actor being located between other actors	Measures potential control an actor has over network information flow. Calculated on binary (unvalued) data.[37]

Distance	Actor	Number of ties between two actors. Directly connected actors have a distance of one	Captures efficiency of transmission of information through network[37]
	Network	Various indexes created from actor-closeness ex: Freeman's [87] Closeness Centrality: Average distance actors are from all other actors [43]	Important to calculate variance
Reachability	Network	Number of steps maximally needed to reach from one actor to any other actor in the network	Captures fragmentation/cohesion.

2.6.1.7 Comparing Social Networks

There are a range of methods for comparing networks through testing for significance and exploring stochastic models of network structure [37]. The majority of these methods are only possible when comparing networks among the same set of actors. The bootstrapping methods described by Snijders and Borgatti and Multidimensional scaling are exceptions. These developments—dynamic models, significance testing and longitudinal analysis are arguably the most important—although still in development— advances in SNA since the 1960s [36].

2.6.2 Network Characteristics and Performance

Studies that go beyond describing professional advice networks and seek to associate network metrics with performance are limited. Those studies that do so within the health sector form an even smaller subset and most define performance as adoption of best practices rather than linking to health outcomes. There is a growing body of literature around network interventions for health, asserting that certain network configurations yield improved outcomes [41, 42]. Much of that literature focuses on patient networks and behaviour change. Below is a summary the link between these SNA metrics and performance—and where available—focusing on health and/or advice network applications. This has a slightly broader scope than that of the systematic review (paper 1).

Density

Dense networks provide more pathways for communication than sparse ones, which facilitates information exchange and decision making [43]. Network density in its extreme can be a liability

because it can reinforce insularity and impede connections to external information [43]. A SNA of a substance abuse community coalition found lower network density associated with the adoption of evidence based practices, further supporting that higher network density will not necessarily yield desired results [44]. A network diagnostic tool proposes that ideal network density should be between 0.15 -0.50 [42]. A network intervention within community groups aiming to prevent childhood obesity among their members using the diagnostic tool found density of advice and discussion networks increased from one time point to another, which was described as a positive effect, although there was no explicit link to network performance, or health outcomes [42].

Centrality

Shaw's 1970s studies showed that more centralised networks complete tasks more efficiently, however, since then, debates continue regarding centralisation and network performance [43]. Rogers asserts that organisational innovativeness is inversely associated with centrality. Fujimoto studied health coalition networks and found centralisation positively associated with adoption of evidence-based practices [45].

In-degree centrality, the most frequently used network measure of opinion leadership, has been associated with adoption [43, 46, 47]. Rogers' found opinion leaders were more likely to be earlier adopters than non-opinion leaders [48]. Several studies found physician opinion leaders effective tools for speeding up network adoption of guidelines [49-51]. However, Fattore *et al.* found no relationship between an Italian doctor's degree centrality and performance [52]. In spite of previous literature indicating more central actors have information advantages that positively influence individual performance [53-56].

Distance/Reachability

Average path length (APL), a slightly different metric than reachability or distance, is the average of the distances between all nodes in a network. A low APL indicates cohesion within the network, with little clustering. Clustering can accelerate intragroup spread (of diseases, behaviours, information), but inhibit intergroup spread [43]. Mascia, *et al*. found that cohesion may hamper self-reported physician adoption of evidence based medicine in Italian doctors [57].

Network size

Rogers reports that organisational size is highly correlated with innovativeness [48]. A larger network may provide more opportunities for the introduction of new ideas, however it is inversely related to density, which may impede communication throughout the network.

Core-periphery

This structure involves a group of densely connected nodes, the core and a group of less densely connected nodes, the periphery. The degree to which the data exhibit this structure is determined by fitting a core-periphery model to the data [43]. Gainforth, *et al.* found a core-periphery structure among staff at a community-based organisation serving spinal cord injury patients, with membership to the core associated with knowledge of guidelines [47].

Brokerage/Tie Strength

Weak ties are important for diffusing new information and strong ties reinforce adoption, therefore both have roles in information sharing [48, 58-60]. Explicit knowledge is best shared through networks with high levels of brokerage and hierarchy, while tacit knowledge is best shared through highly dense networks [58, 61]. A recent systematic review of brokerage in collaborative networks found few examples in healthcare contexts, however did conclude that brokers who can span a structural hole and bring information to otherwise isolated clusters would be valuable in collaborative healthcare contexts with divides across cadres and sites [62]. That said, brokers across structural holes are a less efficient route to information sharing than densely connected networks [48, 62]. A systematic review identified 13 studies looking at structural holes in health care networks, only one of which linked structural holes to improved performance [63, 64]. However most studies do not link to performance, for example: Creswick and Westbrook in 2010 used betweenness centrality to identify strategic individuals who can act as brokers in a descriptive study of medical advice seeking among healthcare workers in a renal ward of an Australian teaching hospital, however there was no link to performance [65].[4]

Homophily

Information flows more readily between individuals of similar background and networks are prone to homophily [66, 67]. Zheng, *et al.* found the importance of homophily and friendship networks in physician adoption of electronic health records systems [68]. However, novel information typically originates from those outside your immediate network who are more likely to be different from you and have different knowledge [48]. A recent study of health policy networks in Burkina Faso surprisingly found homophily not to be a factor relevant for evidence sharing [69].

While much research has been done to identify network properties, roles and information flow, the evidence base for specific network properties association with health system performance

[4] Creswick and Westbrook later published a study in 2015 that included a link to patient outcomes, as reflected by that study's inclusion in Paper 1.

is weak. This body of work aims to explore the literature further and conduct a study that will contribute towards addressing that gap.

2.6.3 Social Network Analysis applications in Health

There is a long standing history of social network analysis in health, [70] with some of the seminal articles being health related. Coleman, Katz and Menzel looked at the adoption of tetracycline by US physicians [71]. Yet, some suggest that social network analysis has not fully realised its potential in health, particularly in applications outside of traditional hospital settings, among community-based healthcare workers, in health systems research and in low and middle income contexts [34].

A review of SNA history, methods and applications to health in 2007 found that much of the work to date focused on spread of disease, diffusion of ideas, impact of social networks on individual health behaviour and inter-organisational structure of health systems [72]. Luke and Harris grouped use of network analysis in public health into three categories: transmission networks, social networks and organisational networks [72]. Transmission networks could be further broken down into disease and information transmission networks with disease transmission focusing on sexually transmitted diseases and infections and outbreak applications. SNA studies were further subdivided into those studying network associations with individual health behaviours, and the roles of social support and social capital in health outcomes. These findings are supported by literature reviewed in preparing this protocol. Health SNA studies have looked at peer groups to influence health behaviours such as smoking[73] [42], drug use [74], mammography uptake [75], family planning uptake[76] and mental health service uptake. Luke and Harris noted in their recommendations for future research that outside of diffusion of innovations, we know little about how social networks shape professional communication among health professionals [72]. We do know from a systematic review focusing on health professional networks and quality and safety that cliques, professional and gender homophily and over-reliance on central agencies or individuals can be counterproductive [67].

Research on health care worker advice networks has mostly been descriptive [65, 77, 78]. Van Beek looked at the association of advice networks with HCW job satisfaction [79]. Rangachari looked at communication networks of low performing ICUs, but in the absence of comparing to higher performing ICU it is not possible to connect performance to SNA networks [61]. Meltzer used hypotheses about network metrics to develop hypothetically superior quality improvement teams based on network principles, but in the absence of testing these teams there is no explicit link to performance [80]. Shearer looked at three health policy networks in Burkina Faso and assessed network properties and their use of evidence, they found hierarchical

information flow, evidence use positively associated with actor centrality and surprisingly, a lack of homophily [69].

2.6.4 Social Network Analysis in Ethiopia

Few social network analysis studies have been conducted in Ethiopia, less so in the health sector and none in community or primary health care settings. What has been studied using SNA includes social capital of urban poor women [81], "health shocks" and poor rural women [82] and organisational network analyses related to reproductive health [83, 84]. The most relevant study looked at social networks of trainees and educators in a health management programme, but these providers operate in a tertiary setting [85].

2.7 Conclusion

The Introduction section provided an overview of the Ethiopian health service delivery context and an overview of Social Network Analysis history, methods, and past applications to complement what is included in the subsequent papers. The next section describes the aims, objectives and research questions for this body of work.

3 Aims

This section of the thesis describes the overall aim of the thesis, specific objectives and research questions.

The overall aim of this DrPH thesis was to apply social network analysis methods in order to understand the relationship between healthcare worker professional communication and performance.

To achieve this aim we had two objectives and associated research questions, summarised in the table below

Table 5: DrPH Thesis Research Objectives and Research Questions

Objectives	To understand the evidence on which SNA methods that have been used to study professional communication and performance among healthcare providers.	To describe the properties of health care worker professional advice networks, the content of advice exchange, the context in which advice exchange took place and the extent to which the existing advice networks met healthcare worker needs in Ethiopia.

Research questions	Primary research question: • What SNA methods were used to study professional communication and performance among healthcare providers? Secondary research questions: • Did professional communication improve health outcomes? What professional communication network properties were associated with health outcomes? • What methods were used for which types of research questions? • What were the main limitations of the SNA methods? • What was the quality of these studies? • What was the quantity of SNA studies? What was the evolution over time? • To what extent did this research take place in low and middle-income countries? • To what extent did this research focus on community-based health providers?	Primary research questions: • Did informal professional advice networks exist among PHCU healthcare workers? • Were there differences across PHCUs in the network structure, composition and use of professional advice networks? • Describe the range of PHCU health care worker advice network structures and metrics. • Who was sought for advice and why? • What were the reasons for advice exchange? What was the content of the advice exchanged? • What was the context surrounding advice exchange? • Did existing advice networks meet the needs of health care workers? • What were the barriers and facilitators to seeking, receiving or providing advice? Secondary research questions: • How did the above network measures relate to PHCU performance (as measured by health coverage data—ANC visit, PNC visit or facility delivery) • Were HCW professional advice networks restricted to the PHCU? If not, who are these individuals? Under what circumstances are they engaged?

4 Methods

The methods included in this section here focus on details not included in the papers.

4.1 Systematic Review

Please see Paper 1 and Annex 1 for a comprehensive explanation of the methods.

4.2 Ethiopia Network Study

Please see Paper 2 for a more substantial discussion of the methods. Here we have expanded on subjects only briefly handed in the paper.

4.2.1 Selection criteria

The network study had two waves of data collection and therefore two sets of selection criteria. The first wave of data collection required identifying a set of PHCUs. The second wave of data collection required 1) identifying four of eight of those previously selected PHCUs to participate the qualitative study and 2) identifying which 5 individuals from each of those four PHCUs would be asked to be interviewed. Specific selection criteria can be found below.

4.2.1.1 PHCU selection criteria

The CBNC baseline data from Health centres formed the basis for the selection of PHCUs for inclusion in the Ethiopia Network Study. The intention behind the purposive selection was to identify a diverse group of PHCUs with respect to volume of health facilities, level of support, coverage of MNH services and regional representation (from the Agrarian regions). Selection was not intended to be representative. We limited the pool to those facilities from which we had data and that were included in the CBNC midline which had implemented CBNC. The rationale for this was that we would have more data to assess performance should there be data quality concerns with performance data collected during the Ethiopia Network Study. This gave us 26 PHCUs from which to select 8 for participation in the study.

Four metrics were used to guide PHCU selection: Number of health facilities in PHCU, ANC coverage, PNC coverage and a Support Scale we developed using several indicators. Regional representation from all four of the Agrarian regions also influenced selection.

Number of Health facilities in PHCU. Across the 26 PHCUs, the number of health posts per PHCU ranged from 2-9 with an average of five.

Coverage. For coverage we used number of first ANC visits (“ANC 1”) at the health centre as the numerator. We limited the numerator to health centres because HEW at Health Posts are supposed to refer pregnant women to the Health Centre in order to perform the lab tests

needed for ANC. The denominator was the expected number of pregnancies (adjusted for the time period) in the area covered by the health centre and health post. Given we excluded health posts it likely underestimated actual ANC 1 coverage, however when we included the HPs many percentages jumped to over 100%. We suspected data quality issues and variability in respondent interpretation of the questions (the HCs responses may have been inclusive of HPs data already) as the data were not validated onsite during collection as part of the baseline.

For the PNC coverage estimate, the numerator was both HC and HP and the denominator is the same as the one used for ANC. Even though this should have led to an underestimate for PNC (a more accurate denominator would have related to live births), PNC was suspiciously high. The Ethiopia Country Coordinator for IDEAS noted that there was movement towards including those delivering in a facility as having had their first PNC visit. There were likely data quality issues and inconsistencies across the PHCUs in how this was captured.

Given how we used these data just for selection we were interested in relative coverage. We dropped facility delivery as recent policy changes may have affected data validity.

Support Scale. Data points that fed into the support scale included:

- Supportive supervision received (This captures visits from other levels to the health centre in the previous 3 months—an imperfect metric as they could still be adhering to guidelines for visits from higher levels in the system but not have been captured within this time period). Scale 0-2, with 0 being no supportive supervision given.
- Supportive supervision given—(This captures visits from the Health Centre to the Health Posts—indicates the degree to which the PHCU is effectively meeting its internal support monthly visits) Scale 0-2, with 0 being no supportive supervision given.
- Ratio of HCWs to Health facilities (inclusive of all staff reported at health centre and health posts) range 1.8-4 among selected
- Infrastructure (availability of water and mobile phone reception on the day of the survey) 0= neither available, 1= one available, 2= both available
- Support received from an NGO. No=0, Yes=1
- In the last 6 months has the health centre convened a performance review and clinical mentoring meeting. No=0, Yes=1

Initially we had “electricity available on the day of the survey” incorporated into the infrastructure tally. Ultimately, we excluded it as it wouldn’t necessarily indicate level of infrastructure given the frequency of power outages.

Regions. Phase I of CBNC was implemented in the Agrarian regions of Ethiopia, thus this study is focused on those 4 regions. While this may seem like a major limitation, 89% of the HEP is the Agrarian HEP version, in these 4 regions where approximately 80% of all Ethiopians live. These regions are: Oromia, Amhara, Tigray and SNNP. There are marked differences between these regions, linguistically, culturally and administratively. Therefore the selection criteria was specified to ensure equal representation across all four regions with two PHCUs selected per region.

Selected PHCUs.

- **Oromia.** The two PHCUs selected seemed to be different in their coverage and level of support (one received NGO support and the other not). They were from the same woreda.
- **Amhara.** All health centres which met the selection criteria were from one zone. One received NGO support, the other did not. One performed slightly above average while the other was below average. The one that performed slightly better received below average levels of support, whereas the other received average levels of support.
- **Tigray.** There were only two health centres that met the criteria (baseline and midline). They both had above average ANC and PNC coverage. One had only two facilities and the other five. One had above average levels of support (the one with fewer health facilities) and the other only average
- **SNNP.** One had higher levels of coverage than the other, even though they both had low levels of support. The higher coverage PHCU had fewer health workers for the same number of facilities. Data were likely of poor quality as the percentages for ANC and PNC were well over 100. They were from different zones

Overall. The selected sites include 8 health centres from five zones, four regions based on the data available at the time, included approximately 142 health care workers based in 39 different facilities. An average of 17 healthcare workers were based at an average of 4.8 facilities per PHCU. Ratio of healthcare workers to health facilities ranged from 1.8 to 4. Five of the 8 health centres received NGO support, all were government owned health facilities (no variation across the pool of 26 Health Centres/PHCUs). Please see Annex 12.9 for the selected PHCUs and their diversity with respect to coverage of ANC and PNC and support scale.

4.2.1.2 Qualitative inquiry participant selection

The selection of PHCUs and individuals for the qualitative interviews was purposive, guided by network findings to be explored. All of the four regions represented in the network study were included in the qualitative study. Selection of PHCUs was determined by a review of network

properties detected with selection geared towards representing the diversity of patterns observed in conjunction with a review of the performance data. See Annex 9 for the summary of the PHCUs selected for the qualitative inquiry.

Approximately five individuals for each of the four PHCU selected were identified for interviews. Respondents selected represented the range of network roles, cadres, experience levels and years in current role as well as engagement in the advice exchange network and use of off-roster advice networks. The most and least involved HEW in advice exchange was selected from each PHCU. Some HCWs at health centres were not routinely involved in maternal and newborn care, hence why those least involved in advice exchange was limited to HEWs.

Replacements were selected in advanced should the originally selected individuals not be available or have been transferred to another PHCU. The reasons for using a replacement were documented on tools called “PHCU Coversheets.” These can be found in Annex 11.

4.2.2 Pre-testing

The SNA quantitative tools were pre-tested by the candidate on two separate occasions prior to training. During those pre-testing sessions qualitative questions were also asked to inform the development of the qualitative inquiry.

The tools were initially drafted in English and translated into three languages, Oromifya, Tigrinia and Amharic. The tools were translated by two translators and discrepancies reconciled by JaRco Consulting. The translations were reviewed by the interviewers who were native speakers and adapted after pre-testing during the interviewer training.

4.2.3 Training

Given the linguistic diversity captured by the study, at a minimum we required two teams of researchers. The quantitative SNA survey involved training four interviewers and two supervisors to field the two research teams. The training involved an introduction to social network analysis, the study goals, data quality concerns specific to Social Network Analysis, research ethics, obtaining informed consent and reviewing the study tools. Supervisors were given additional training on data management and quality control measures. The training spanned three days including pre-testing and tool revision.

After training for the quantitative network survey, the two research teams went to the first PHCU to collect the data together under direct supervision of the candidate. In the evenings we reviewed the data collection procedures and discussed what worked well and what was challenging. After the first two days of data collection, the observing research team continued onward to collect data at their PHCUs.

For the qualitative follow up interviews, the two supervisors who were involved in the previous wave of data collection served as interpreters. Two researchers were individually orientated to the study by the candidate over the phone and in person prior to the official training. A one-day training took place which reviewed the study roles, protocol, purpose, data collection methods, research ethics, informed consent, data collection tools and the data collection process. It also included an interaction session on how to conduct an interview. The interviewers both had master's degrees from internationally respected institutions and the interpreters had been the supervisors for the quantitative network study as such were familiar with the study, hence why training was compressed.

4.2.4 Data Collection Procedures

Supervisors managed securing approval letters from the different levels of the health system, introduced the research team to the PHCU, completed the roster at the health centre, supervised data collection by interviewers, repeated 10% of all interviews and completed the PHCU cover sheet (see Annex 8) summarising the data collection process within each PHCU.

Interviewers obtained informed consent and administered the survey to all staff within the PHCU.

For the qualitative interviews, the research was staggered with one team sent out immediately following the training and the other started one month later. There was a delay in part due to changing availability of the trained research team. However, the interviewer for the second research team was involved in reviewing the expanded field notes for the first research team and therefore was engaged throughout and learning from the experiences of the first research team.

4.2.5 Data Management

Supervisors managed the rosters, surveys, health centre and health post performance data, informed consent and PHCU cover sheets (a data collection tool that summarised the experience in the field) in the field. Once back in Addis all paper forms were scanned at JaRco Consulting, Ltd. The candidate entered the paper data twice and reconciled differences. Informed consent documentation is kept at JaRco Consulting, Ltd. in accordance with the study protocols.

For the qualitative inquiry, the interviewers wrote expanded field notes in Microsoft Word. De-identified electronic files were shared with the candidate for review and analysis. Audio recordings of the interviews are kept on file at JaRco Consulting, Ltd. along with written documentation of informed consent.

4.2.6 Ethical clearance & considerations

Ethical approval was obtained by the LSHTM review board and the Ethiopia Ministry of Science and Technology prior to data collection. Approval letters can be found in Annex 2 and 3.

Written informed consent was obtained from all study participants and all participants were provided with a participant information sheet containing study details and local study management contacts.

4.2.7 Quality control measures

This section described the quality control measures beyond those contained in the second paper.

A detailed field guide was prepared and used during training for both the quantitative network survey and for the subsequent qualitative interviews. During the training on the network survey tools it became obvious that additional guidance was needed. A description was prepared to clarify what was meant by "advice" and standardise how it was described to study participants.[5]

Separately during pre-testing we learned of specific circumstances that could create confusion regarding who to include on the roster given staff transfers, leaves of absence. A field guide supplement was developed with very specific instructions regarding who to include on a roster based on how long ago they left the facility or duration of their leave.

The description of advice exchange and the one-page supplement to the field guide were designed to support consistency in understanding and application of the tools in the field.

4.2.8 Qualitative Data Analysis

The expanded qualitative data analysis steps were as follows.

- I read through all of the interview expanded field notes in word.

[5] Description of Advice exchange: We are interested in learning about who you go to for advice and who comes to you for advice. We are interested in advice exchange between health care providers. These providers can be midwives, nurses, health officers and HEWs. Typically, they are not community members, unless they are volunteers or traditional birth attendants who work with pregnant women and/or newborns. Not all supportive supervision visits will have advice exchanged. Please do not just tell us when you saw someone during a supervision visit. If you conducted a supervision visit, we are only interested to know if someone asked you for advice specifically during that visit. Not all patient referrals involve healthcare workers exchanging advice. Sometimes before patients are referred to other facilities advice is exchanged between healthcare workers. We are only interested in including referrals if advice is exchanged.

- I developed a short list of basic codes, with definitions based on review of literature, understanding of the subject area and initial read of the interviews.
- I imported the data into MaxQDA and added the preliminary coding framework.
- I applied the codes to two of the interviews. I revised code list and definitions
- I applied the codes to half (10) of the interviews. I paused and revisited the codes and code memos and adjusted as needed.
- I applied the final list of codes to all 20 interviews.
- I then reviewed the data by code, taking notes on emerging themes
- Then I looked at the intersections of codes, noted emerging themes and looked for patterns among and between codes.
- I then revisited the quantitative data to see if there were consistencies in what was reported by individuals in the SNA survey and in the qualitative interviews. I did not expect everything about advice networks to remain the same as data were not collected at the same time and there were staffing changes. Broad themes were expected to be consistent.
- Finally, I reviewed themes with other researchers involved with the study.

4.2.9 Role of JaRco Consulting, Ltd.

JaRco Consulting, Ltd was subcontracted by IDEAS to be the Measurement, Learning and Evaluation partner for their evaluation work in Ethiopia. As such, it was through partnership with them that I managed the operational components of the Ethiopia Network Study. JaRco Consulting, Ltd's Director, Tsegahun Tessema served as the local PI on the study protocol submitted to the ethics board in Ethiopia. As such he reviewed the study protocol I developed and approved the proposed data collection and management procedures. Shimaljash Braha, a research manager at JaRco Consulting, Ltd reviewed the study protocol training materials I developed (the field guide, data collection tools and materials for use during the training) and provided support to the field researchers from Addis and managed the data once it arrived in Addis until I could come enter and analyse the dataset. JaRco managed the translation of the data collection tools, supplied enumerator CVs for my review and approval, provided the facilities for training and the vehicles and drivers for the field work. They managed the study logistics related to following up on my visas so that I could come meet with FMOH staff to discuss the study protocol, train enumerators and come enter and analyse the data. They physically house copies of the data collected and participant information sheets as per the study protocol. Their support was invaluable to the conduct of this study.

4.3 Conclusion

The methods section provided more detail for the methods used in the Ethiopia Network Study, beyond what is included in Paper 2. Specifically, more information was presented on selection criteria, pre-testing, training, data collection procedures, data management, ethical clearance, quality control measures and qualitative data analysis steps.

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London School of Hygiene & Tropical Medicine
Keppel Street, London WC1E 7HT
www.lshtm.ac.uk

Registry
T: +44(0)20 7299 4646
F: +44(0)20 7299 4656
E: registry@lshtm.ac.uk

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SECTION A – Student Details

Student	Kate Sabot
Principal Supervisor	Joanna Schellenberg
Thesis Title	The use of social network analysis to study health care provider advice and performance

If the Research Paper has previously been published please complete Section B, if not please move to Section C

SECTION B – Paper already published

Where was the work published?	Systematic Reviews		
When was the work published?	23 October 2017		
If the work was published prior to registration for your research degree, give a brief rationale for its inclusion	N/A		
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For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	I conceptualized research questions, wrote protocol and registered the review with PROSPERO. I ran the searches in all of the databases. I screened titles, abstracts and full text articles and reviewed outcomes with the other screener. I developed extraction tools and critical appraisal tools. I extracted data using those tools and reconciled extractions

	with other extracter. I was the primary writer of paper text, integrating feedback from co-authors. I managed journal submissions and responses during the peer review process.

Student Signature: [redacted] **Date:** 24 October 2017

Supervisor Signature: [redacted] **Date:** 24 October 2017

6.1 Permission to reprint

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6.2 Use of Social Network Analysis methods to study professional advice and performance among healthcare providers: A systematic review

Authors:

Kate Sabot[1 2*] kate.sabot@lshtm.ac.uk

Deepthi Wickremasinghe [1 2] deepthi.wickremasinghe@lshtm.ac.uk

Karl Blanchet [3] karl.blanchet@lshtm.ac.uk

Bilal Avan [1 2] bilal.avan@lshtm.ac.uk

Joanna Schellenberg [1 2] joanna.schellenberg@lshtm.ac.uk

[1]The Centre for Maternal, Adolescent, Reproductive and Child Health (MARCH), London School of Hygiene and Tropical Medicine, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK

[2]Department of Disease Control, Faculty of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK

[3]Department of Global Health, Faculty of Public Health and Policy, London School of Hygiene and Tropical Medicine, London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK

*Corresponding author kate.sabot@lshtm.ac.uk

Abstract

Background

Social network analysis quantifies and visualizes relationships between and among individuals or organisations. Applications in the health sector remain underutilized. This systematic review seeks to analyze what social network methods have been used to study professional communication and performance among healthcare providers**.**

Methods

Ten databases were searched from 1990 through April 2016, yielding 5970 articles screened for inclusion by two independent reviewers who extracted data and critically appraised each study. Inclusion criteria were study of health care worker professional communication, network methods used, and patient outcomes measured. The search identified 10 systematic reviews. The final set of articles had their citations prospectively and retrospectively screened. We used narrative synthesis to summarize the findings.

Results

The six articles meeting our inclusion criteria described unique health sectors: one at primary health care level and five at tertiary level; five conducted in the United States, one in Australia. Four studies looked at multidisciplinary health care workers, while two focused on nurses. Two studies used mixed methods, four quantitative methods only and one involved an experimental design. Four administered network surveys, one coded observations and one used an existing survey to extract network data. Density and centrality were the most common network metrics although one study did not calculate any network properties and only visualized the network. Four studies involved tests of significance, two used modelling methods. Social network analysis software preferences were evenly split between ORA and UCINET. All articles meeting our criteria were published in the past 5 years, suggesting that this remains in clinical care a nascent but emergent research area. There was marked diversity across all six studies in terms of research questions, health sector area, patient outcomes and network analysis methods.

Conclusion

Network methods are underutilized for the purposes of understanding professional communication and performance among health care providers. The paucity of articles meeting our search criteria, lack of studies in middle- and low-income contexts, limited number in non-tertiary settings and few longitudinal, experimental designs, or network interventions present clear research gaps.

Systematic review registration: PROSPERO CRD42015019328

Keywords

Social network analysis, health outcomes, health system performance, professional advice, professional communication, healthcare workers, network analysis, systematic review

Background

In 2015, the Millennium Development Goals (MDGs) expired after 15 years of galvanizing the global development community around health targets related to women, children and HIV and AIDS. Their replacement, the Sustainable Development Goals (SDGs) broaden global focus beyond health.[1] As such, the health sector will need to explore new ways to influence provider practice and scale up best practices to meet the outstanding MDG targets and improve health outcomes. Understanding and harnessing the power of existing professional advice networks among health care providers could assist in influencing provider practice and improving health outcomes in low- and middle-income countries (LMIC). Social network analysis focuses on studying relationships between and among individuals (or organizations) who are connected by one or more ties of interdependency, such as love, friendship, kinship, trust, collaboration, or communication [2]. Social network analysis (SNA) can lend insight into defining, measuring and understanding these professional communication networks and therefore designing effective network interventions to improve provider performance and ultimately, health outcomes [3, 4].

SNA is defined as a means of mapping and exposing channels of communication and information flow, collaboration and disconnection between people [5]. SNA is both a theory and a methodology that has generated a body of empirical research [6, 7]. One of these theories is diffusion of innovations defined by Rogers as the "process by which an innovation is communicated through certain channels over time among members of social system."(p.5)[8]. Rogers proposed that individuals go through several stages in deciding to "adopt" an innovation; a process influenced by the characteristics of innovations, specifically the complexity, triability, observability and the relative advantage conferred by the innovation [8, 9] .Individual adoption of an innovation can be expressed as a normal distribution, segmenting individuals into categories of individual innovativeness: innovators, early adopters, early majority, late majority, and laggards [8].

Professional behaviour change among health care providers is often referred to as knowledge translation or transfer. We hypothesize that certain network structures and the presence of network roles within networks of health care providers can facilitate diffusion of innovations, or knowledge translation and transfer, particularly where the issue is lack of provider information, and that may in turn change practices and improve patient outcomes. Admittedly, this is a simplification as relationships among health care providers are multiplex and friendship or trust networks rather than purely professional communications may be more influential in changing provider behaviour when there is informational ambiguity [10]. As such, it is important to consider both formal and informal professional communication in an attempt to mitigate this concern.

While it is not possible for this paper to include a comprehensive overview of social network analysis study designs, data collection and data analysis methods, key concepts are highlighted and further explanations can be found elsewhere [2]. Social network analysis studies are defined primarily as either whole network, including all members of a group defined by a specified boundary or ego network studies, capturing the networks of select individuals within a network. Hybrid models can combine elements of both approaches. All networks are characterized by whether the network is "directed", indicating the

orientation of the relationship, for example if A influences B, then the tie would include an arrowhead at B or "undirected" where the relationship either exists or does not and none of the ties or lines have arrowheads. They are also either "valued" capturing the intensity of the relations on a scale, or "unvalued", whereby these relations are dichotomous. Network data can be captured through questionnaires, interviews, observations, existing records, diaries or other methods [2]. Other data collection methods or ways of generating networks of providers include journal publication co-author lists, identifying patient-sharing among providers, attendance at conferences, participation on social media forums, to name a few.

Social network analysis data analysis method options depend on how the data were collected and the research questions of interest. In SNA, visualizing data is both a means of presenting findings as well as a tool for generating additional findings. Quantification of network properties are subject to certain constraints as the unit analysis is a relationship between actors (individuals or organizations) rather than independent observations. Thus, SNA requires analytical tools that do not rely on independence of observations or relations [2]. Analysis can be at the actor, subgroup or network level. Common subgroup structures are dyads, triads, clusters, cliques, components and bridges [11]. Many network metrics can be calculated including: degree, density, centrality, reachability and distance. Some of these can be calculated at the network or actor level or both. Gesell, *et al.*, recommend calculating isolates, degree and reciprocity at the actor level and at the network level: presence of sub groups, density, centralization, transitivity and cohesion as the metrics most likely to have effect on individual and group processes [12.

A 2012 systematic review of SNA applications in healthcare settings concluded that SNA's potential has been unrealized in the health sector, particularly because virtually all identified studies were simple network descriptions rather than studies of network interventions [5]. This review had a definition of a healthcare setting that excluded community-based health workers and interventions, a limitation particularly relevant in LMIC and global health.

The present systematic review builds on the Chambers, *et al.*, [5] review in the following ways: broadening the definition of "healthcare settings" to be inclusive of community-based settings, expanding the databases and search terms, and updating the searches to include articles from 2011-2016. The focus of the review synthesis is substantively different looking specifically at SNA methods used to understand healthcare provider communication and performance. The primary research question this review sought to address is: what SNA methods have been used to study professional communication and performance among healthcare providers? Secondary research questions included:

- Does professional communication improve health outcomes? What professional communication network properties are associated with health outcomes?
- What methods have been used for which types of research questions?
- What are the main limitations of the SNA methods?
- What is the quality of these studies?
- What is the quantity of SNA studies? What was the evolution over time?

- To what extent has this research taken place in low- and middle-income countries?
- To what extent has this research focused on community-based health providers?

Methods

DEFINITIONS

For any systematic review, it is critical to clarify our meaning when using terms that define a search strategy. For this review, we have operationally defined "healthcare providers", "professional communication" and "performance" as follows.

In this context, we defined "healthcare providers" as physicians, clinical officers, nurses, midwives, counsellors, physician's assistants and others who provide health-related services to patients in formal medical environments. Additionally, community-based cadres such as community health workers, village health workers, traditional birth assistants and others were also considered healthcare providers.

For our purposes, we defined "professional communication" as formal or informal professional advice seeking or giving or discussion about hypothetical or actual work situations or patients. For example, studies exploring friendship networks of healthcare providers were not considered eligible, unless they also captured communication related to work situations or patient care and documented patient health outcomes.

We defined "performance" as a study including a patient health outcome. Studies that only considered "patient satisfaction" or health care provider "perceptions of performance" were not eligible for inclusion.

SEARCH STRATEGY

The search strategy focuses on the intersection of SNA and diffusion of innovations, the term used in the SNA community most relevant for professional communication related to knowledge sharing and transfer. Since health policy and health systems research often use "knowledge translation or transfer" language, the search strategy also includes the intersection between those terms and SNA. As a methodologically-focused review, this review will highlight the range of SNA methods applied.

To address the research questions, the systematic review focused on three concepts that are integral to the primary research question: 1) SNA 2) diffusion of innovations and 3) knowledge translation and transfer. The key terms for these concepts are shown in Additional File 1 and truncation search terms will be used to make the search inclusive.

Concept 1: Social Network Analysis

The search strategy for the SNA concept was adapted from the Chambers, *et al.'s* scoping systematic review of Social Network Analysis and healthcare settings [5]. This was particularly helpful guidance as a more recent SNA review, Cunningham, *et al*. noted the challenge of "social network" yielding irrelevant social media or social support articles [13]. One of the changes from the Chambers *et al.* review was an expansion of the list of SNA software listed (from four: UCINET, NetDraw, Pajek and

KrackPlot to 56), which was guided by a chapter in the SAGE Handbook of Social Network Analysis.[14] Depending on the database, specific software packages (Blanche, InFlow, Jung, ORA, ORS, Pnet, Puck UNISoN, SNAP and STRUCTURE) were excluded as they yielded thousands of off-topic articles. See Additional File 2 for a list of exclusions by database. None of these exclusions were the SNA packages included in the previous review and for the most part are not the most commonly used software packages for SNA. The one exception is ORA, a SNA software package that, for 6 of 10 databases, returned thousands of articles that used odd ratios in their analysis. However, as this review still yielded two studies that used ORA we do not feel that this negatively impacted the search.

Concept 2: diffusion of innovations

The search strategy for the diffusion of innovations concept was influenced by the original search strategy used as a starting point for a meta-narrative on *Diffusion of Innovations in Health Service Organizations* [15]. However, the focus on health service organisations was seen as potentially too limiting. Therefore, terms related to health service organisations were not included to let the review capture a broader range of studies. “Diffusion of innovations” is a phrase that is relatively new to health systems research. Consequently, the review used a third concept to ensure all relevant studies were captured, which corresponds to diffusion of information: knowledge translation and transfer.

Concept 3: knowledge translation and transfer

Knowledge translation and transfer (KT), are terms describing a relatively new discipline, which does not have an agreed upon lexicon. A systematic study of KT terms used in 12 journals found inconsistent use of KT terms such that less than half of what the authors classified as “KT articles” used the presumed “KT terms” leading the authors to refer to the situation as a “tower of babel” [16]. The search strategy for this concept was developed by determining the common terms across six sources including four systematic reviews [17-20] and two articles on knowledge translation “KT” or “K*” terms [16, 21]. A comprehensive listing of all 253 K* terms can be found in Additional File 3. An initial search conducted using all the terms yielded over 6,000 articles in MEDLINE, which led to a revision of the approach for this concept. Priority terms for inclusion in the search strategy were those that appeared in more than one source.

The search strategies were then developed looking at the intersection of concept 1 with concept 2 and the intersection of concept 1 with concept 3. They were then adapted to each of the databases included in the review, including mapping the above terms to MeSH terms. Detailed search strategies for each of the 10 databases are available upon request—an example is included in the Additional File 4.

MEDLINE, EMBASE, PsychINFO, CINAHL, Global Health, Social Policy and Practice, Health Management Information Consortium and Web of Science were searched. Grey literature was searched via Popline. The Cochrane Library was searched to identify other systematic reviews and relevant studies. Several websites were searched including: International Network for Social Network Analysis, American Evaluation Association Social Network Analysis Technical Interest Group and in the International Sunbelt Social Networks Conference proceedings archives.

Articles were downloaded into Endnote X5.0.01, a bibliographic software package and duplicates within and across databases were removed. All 5970 articles were then assessed for meeting study inclusion criteria through a three-stage review process. Two independent reviewers (KS and DW) screened titles, abstracts and full text articles; after each step, discrepancies were discussed and reconciled.

The 10 Systematic reviews identified through the search strategies that addressed SNA had the articles they included screened for inclusion in this review [5, 22-29].

The search strategies were executed originally from 1990 to January-March 2015 and then updated in April 2016, capturing articles published since the original search. All systematic reviews identified had the articles they included screened. The final set of articles had their reference lists screened and SCOPUS was used to conduct a prospective citation search. All articles were subjected to our two independent reviewer, 3 stage screening process. The PRISMA flow chart (Figure 1) reflects the combination of the searches and screenings conducted in 2015 and updated in 2016.

The study protocol was registered with PROSPERO **DOI:** 10.15124/CRD42015019328 URL: http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42015019328

STUDY INCLUSION AND EXCLUSION CRITERIA

A checklist was developed to guide each reviewer. A single "no" response to any of the questions below was a cause of exclusion of the study from the systematic review:

- Does the study use SNA methods?
- Are the study subjects healthcare providers?
- Is the communication/relationship of interest between healthcare providers?
- Does the research focus on professional communication?
- Is there some metric used for performance, defined as assessing patient outcomes?

Only English search terms were used and studies included were limited to those published in English since 1990. This date was selected in part because the previous review, Chambers *et al.*, 2012 had 49 of 52 included articles published after 1990. Furthermore, modern SNA studies rely on software that has primarily existed after 1990.

This review excluded studies conducting SNA of patient-to-patient communication or patient-to-provider communication. Direct-to-consumer advertising and marketing studies, such as pharmaceutical companies marketing to potential patients, were also excluded. Publication or research networks, provider patient-sharing networks, provider friendship networks and non-empiric research were excluded. Studies whose only measures of performance were "provider perceptions" or "patient satisfaction" were excluded as not being an objectively measurable health outcome.

These exclusions were made on that basis that they were not thought to lend insight into methods used to assess professional communications among healthcare workers and their association with patient outcomes.

STUDY QUALITY ASSESSMENT

Two tools were developed for critically appraising study quality—one for qualitative studies and the other one for quantitative study designs. These tools were informed by STROBE, EPOC, CASP, SIGN, ENTREQ, COREQ, RATS, QARI and NICE Process and Methods guidelines and checklists and seminal articles on the subject.[30-40] Systematic reviews of SNAs identified through our search strategy were consulted as there is not a standard tool for assessing the quality of SNA and some of the content of existing checklists for other study methods do not apply for network studies [5, 13, 22-29]. However the existing tools were useful starting points for assessing the quality of studies. See Additional File 5 and 6 for the tools developed to assess qualitative and quantitative studies and Table 2 for the summary of study quality. As per Cochrane and SIGN guidance studies were assessed as being high, medium and low quality with no summary score produced or a quality threshold for inclusion in the review [36, 41]. Mixed-methods studies had both tools applied and an overall study quality assessment provided drawing on both tools' assessments.

Selected studies were independently critically appraised using these tools by two individuals (KS and DW). Discrepancies were discussed until reconciled.

DATA EXTRACTION STRATEGY

A data extraction matrix was developed after reviewing data extraction tools used in relevant systematic reviews and consulting with a SNA and health expert [5, 13, 22-29]. The tool was pilot-tested and revised for greater clarity and specificity with the final version covering 35 data points. Data were extracted independently by two individuals (KS and DW), results compared and discrepancies discussed and resolved by consensus. See Additional File 7 for the tool and Tables 2,3,4,5 and6 for a subset of the data extracted.

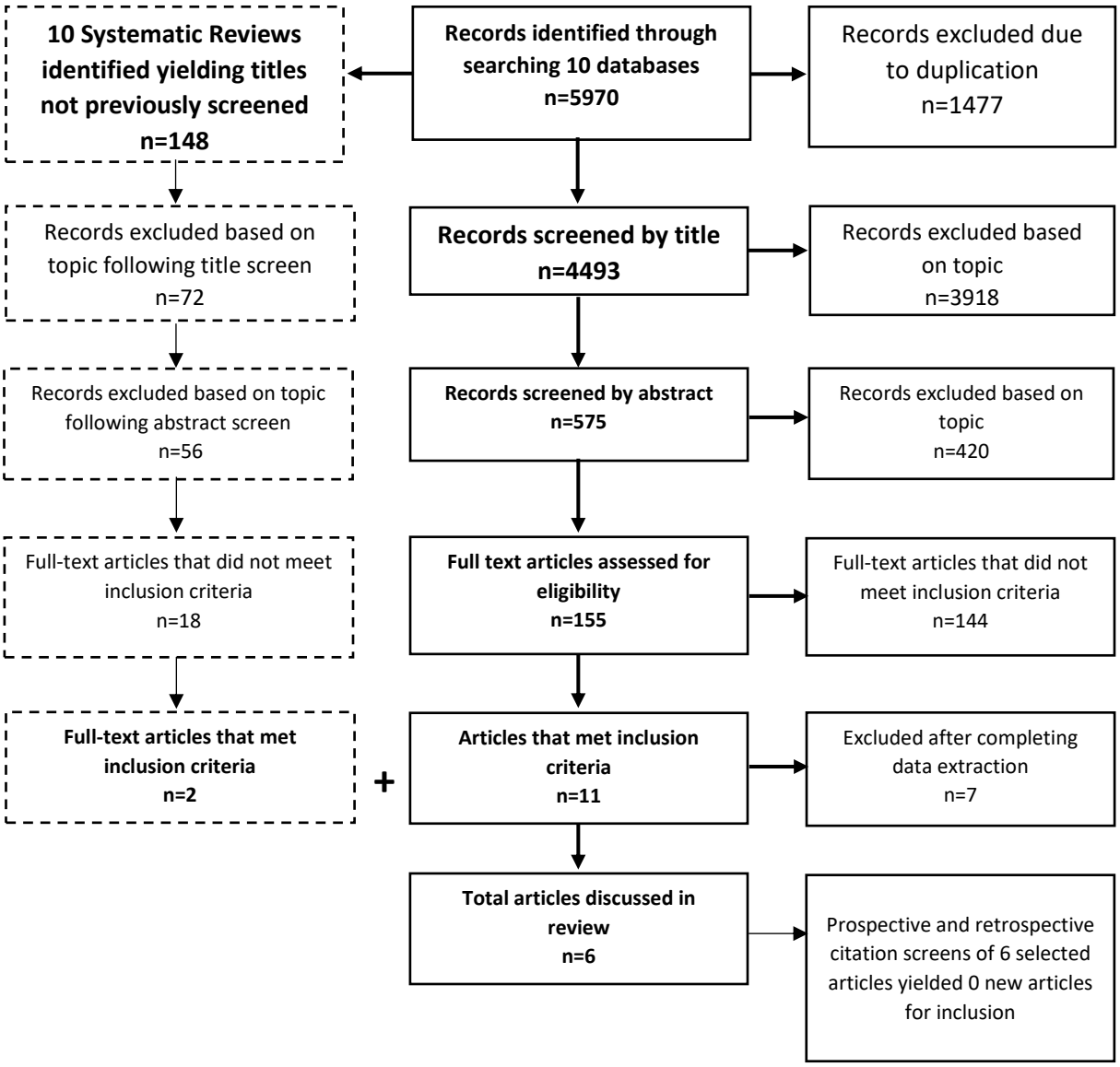
DATA SYNTHESIS AND PRESENTATION

Narrative synthesis was used to describe studies included in the review, focusing on the SNA methods and metrics used [42].

Results

Our searches returned 5970 articles, which after double screening yielded six articles meeting our inclusion criteria.[43-48] Figure 1 documents the review process using a PRISMA flow chart.

Fig. 1 PRISMA flow chart



Studies' characteristics are described in Table 1. They were primarily recently published (all since 2010), looking at multidisciplinary healthcare providers (4 of 6) and conducted in the US (5 of 6) in tertiary care facilities or their equivalent (5 of 6).

Table 1 Study characteristics

Year of publication	Number	Percent
1990-2000	0	0%
2000-2010	0	0%
2010-2016	6	100%
Country		
Australia	1	17%
United States	5	83%
Type of health facility		
Hemodialysis center	1	17%
Hospital-based	3	50%
Nursing home	1	17%
Primary health care (PHC)	1	17%

Type of health professional		
Multidisciplinary teams	4	67%
Nursing staff	2	33%
Type of patients		
Emergency and outpatient department patients	1	17%
Hemodialysis patients	1	17%
Medical-surgical unit patients	1	17%
Nursing home patients	1	17%
PHC patients with alcoholism	1	17%
Renal and respiratory ward patients	1	17%
Study design		
Experimental	1	17%
Observational	5	83%
Mixed-methods	2	33%
Quantitative only	4	67%
Qualitative only	0	0%

Below, we review findings based on each of our research questions.

Primary research question

What SNA methods have been used to study professional communication and performance among healthcare providers?

Tables 2,3,4,5 and 6 contain extractions from the six studies. Table 2 provides an overview of the studies, Table 3 focuses on their SNA methods, Table 4 lists the SNA metrics used by each study, Table 5 looks at the association between the SNA metrics and patient outcomes and Table 6 explores the relationship between research questions and SNA methods used. Key patterns are summarized below.

All studies included in this review were exploratory in nature. All but one study,[47] employed a cross-sectional study design looking at whole networks. Four studies could only look at one or two whole networks, listing this as a limitation to their study's generalizability [43-45, 47]. Data collection tools were typically network surveys, designed specifically for that study. However, one study coded observations[43] and another study extracted data on health care worker communications from surveys of patients that attended emergency departments[46]. All but one study [47] visualized their networks, which is not surprising as one of the unique aspects of SNA methods and software is the ability to visualize networks. Software preferences leaned towards UCINET and ORA [49, 50] with Microsoft Excel and SPSS mentioned as supplementary tools. A wide range of network metrics were calculated, although density and centrality were the most commonly calculated. See Table 4 below for an overview of which studies calculated specific network metrics. There was a range in how these data were analysed with some integrating them into models and others using tests of significance.

Table 4: Summary of studies' social network analysis metrics

Social Network Analysis Metric	Effken, *et al.*	Lindberg, *et al.*	Alexander, *et al.*	Creswick and Westbrook	Mundt, *et al.*	Hossain and Guan	Total
Centralization		X					1
Centrality (in-degree)	X				X	X	3
Centrality (out-degree)	X						1
Centrality (eigenvector)	X						1
Centrality (betweeness)	X						1
Clustering Coefficient	X						1
Component count strong	X						1
Component count weak	X						1
Connectivity		X					1
Degree						X	1
Density	X			X		X	3
Diffusion	X						1
Fragmentation	X						1
Hierarchy	X						1
Inclusion		X					1
Isolates	X						1
Number of triads	X						1
Number of cliques	X						1
Reach		X					1
Reciprocity				X			1
Simmelian ties	X						1
Tie-strength					X		1
Total	15	4	0	2	2	3	26

Secondary research questions

What is the quantity of SNA studies? What was the evolution over time?

Six studies were identified, with all studies published in the past 5 years and none before 2011. One study was published annually from 2011 to 2013 and then three were published in 2015. The evolution over time suggests there is an increasing interest in this type of study; however, with only six studies it may be a premature assessment.

To what extent has this research taken place in low- and middle-income countries?

Not a single study that met our search criteria was conducted in a low or middle-income country. All studies took place in either the United States [43, 45-48] or Australia[44].

What is the quality of these studies?

The quality of the studies meeting our selection criteria was assessed using the tools found in Additional Files 5 and 6 and summarized in Table 2. None of the studies were found to be of low quality, two were

found to be of acceptable quality and four of high quality applying the SIGN guidelines for assigning these categories.

What methods were used for which types of research questions?

There were only two studies using mixed methods, the other four only used quantitative methods.

Interestingly Alexander *et al.*, only visualized the communication networks and did not calculate SNA metrics [43]. Their authors cited this as a limitation of their design, which did not involve coding the observations in a way that would allow for health care workers to be individual nodes. Yet another study, Lindberg, *et al.,* did not include a visualization of the communication network [47].

Modelling and tests of significance were used when studies intended to measure the association of network properties with other factors. Table 2 lists the study objectives, research questions, study design and data collection methods whereas Table 3 goes into detail regarding each study's SNA methods. Table 4 summarizes the SNA metrics used by each study and Table 6 looks at the link between research questions and study design.

What are the main limitations of the SNA methods?

Table 2 lists the limitations, identified by our reviewers (although some were mentioned by the authors as well) of each of the six studies. While some of these limitations do not relate to the SNA methods, they provide insight into some of the challenges faced by studies using such methods. A general challenge generated by SNA methods is the need to clearly define the study boundary, which can limit sample size and therefore affect the broader generalizability. This came up in several studies noting areas for further research including broadening to other settings and repeating the study elsewhere given the limited sample size. The sample size limitation related less to the number of nodes, but more to the number and type of whole networks included.

The lack of longitudinal and experimental designs speaks to a broader challenge in the field as these are new areas for application of SNA methods and the analytical tools and software are still in development. This limited the ability of SNA studies to address causal pathways.

Similarly, the limited qualitative methods being integrated into the studies constrain the contextual understanding of the network properties quantified and visualized through applying the quantitative SNA methods.

One study, Alexander, *et al.* reported that their coding method limited the type of analyses that can be conducted and therefore they did not analyse their SNA data beyond visualizing patterns [43].

To what extent has this research focused on community-based health providers?

None of the studies took place in a community-based setting. Only one study took place in a primary health care context.[48] The other five studies took place in tertiary level facilities including hospital units and specialist care facilities like haemodialysis centres or nursing homes [43-47].

What are the key findings of these SNA studies?

While this is a methodologically focused review, therefore inherently less focused on any associations observed between network properties and the health outcomes measured, the next question naturally arises, what did these studies find? Their overall study findings are discussed in Table 2, but to better understand any relationship between specific network metrics and patient health outcomes, we looked at the metrics captured in more than one of the studies and their reported association with patient outcomes in Table 5. There were only two metrics, density and in-degree centrality reported in more than one study. For this analysis, all centrality metrics were collapsed into one category, although the actual centrality metrics used in the study are specified in Table 4.

Patient outcomes generally improved when healthcare worker communication was denser and more centralized as measured by various centrality metrics. However, for both metrics studies reported no significant association with some patient outcomes, as such more studies are needed to clarify patterns.

The Effken study had one exception to the relationship proposed between centrality and patient outcomes. Adverse drug events increased with betweeness centrality, possibly due to the presence of gatekeepers the authors hypothesized. Another patient outcome, symptom management on the surface appears to have conflicting associations with centrality metrics; however, the authors suggest that taken together the correlation of this patient outcome metric with eigenvector centrality and patient symptom management capacity with simmelian ties (strong ties within cliques) with could point to the importance of small group communication.[45] This broader pattern of performance being linked to more centralized networks is generally supported by the SNA literature, although the debate continues [51]. Furthermore, patient outcomes may not necessarily be expected to be associated with healthcare provider centrality as they could be central for reasons other than the quality of care or professional advice they provide. Network density can provide more pathways for communication, however in its extreme, can reinforce insularity and limit external sources of information [51]. As such a network diagnostic tool proposed ideal network density to be .15-.50 [12].

There are definite limitations to this specific analysis. Through this process, it became clear that not every SNA metric calculated and its association with all outcomes captured in a study are published. Another complication is that not all of the metrics and results were truly comparable given the different data sources and analytical approaches. For example, one study used GLMM models collapsing all data collected across teams that had different professionals with either strong or weak ties for two types of communication networks (electronic and face to face) rather than looking at the in-degree centrality of a network and its association with the patient outcome of interest.

Discussion

The discussion will focus on the two main research questions of the review, the primary research question “What SNA methods have been used to study professional communication and performance among healthcare providers?” and “What methods were used for which types of research questions?”

What SNA methods have been used to study professional communication and performance among healthcare providers?

The majority (5 of 6) of the studies that met our selection criteria used a cross-sectional, observational study design. This posed challenges in addressing the research questions looking at the association between provider communication networks and patient outcomes, as the patient outcome data timeframe and the networks being captured, were not always temporally aligned.

As other systematic reviews suggested, there remain few network intervention studies, a frontier opportunity for researchers [5, 26, 27]. See Additional File 8 for an overview of the other SNA and health systematic reviews identified through our search strategy and their recommendations for further research. The lone experimental study included in this review, Lindberg, *et al.,* did not use network data to design the intervention, so it does not qualify as a "network intervention" [47].Network interventions and experimental, longitudinal study designs will allow for SNA methods to address causal pathways, a current limitation in how the methods are being applied.[29]

One of the challenges facing researchers wanting to use SNA methods is the lack of validated SNA survey tools for use in the health sector, as highlighted by Creswick and Westbrook and Perkins, *et al*.[29, 44] While this only is relevant for those interested in using sociometric survey methods, as more studies use SNA methods, we can anticipate that a set of tools or best practices for applying a range of SNA methods will emerge. The Perkins systematic review aimed to address one aspect of that gap by gathering all the name generating tools they found across the studies they reviewed [29]. However, this is only one step in the process of having more systematically validated tools and best practices available.

The most obvious pattern in study methods was that studies looking to establish associations used more advanced statistical methods to test their hypotheses whereas the studies that were looking to answer questions about processes used more qualitative methods. However, this observation is largely less about SNA methods and more about the relative strengths of qualitative vs quantitative research methods. The diversity of SNA analytical methods could also speak to the expertise of the individual researchers and which methods they were more comfortable using rather than necessarily a clear advantage posed by using one method over another to answer a given research question. That said there are SNA methods such as Exponential Random Graph Models which are appropriate to answer specific SNA questions that other SNA methods wouldn't be able to address. These methods were not used in the studies meeting our search criteria.

It is important to note that while this review did not identify any studies conducted in LMIC, this does not mean SNA methods have never been used to study health in these contexts. A systematic review looked specifically at SNA applications in LMIC, and found 17 articles from 10 health-related network studies; however, their focus was broad and none of the studies met our criteria of focusing on healthcare provider communication and patient outcomes.[29] Instead, these studies set in 9 countries looked primarily at patients or their household as the ego and used name generators to establish networks related to: contraception use and family planning, mercury consumption (2 studies), HIV transmission (5 studies), and diarrheal disease transmission (3 studies) [29].

One of the issues with the way SNA methods have been applied in the health sector is the often artificial boundaries imposed by limiting studies to specific cadres, which did not reflect the actual care environments. Notably four of six studies looked at multidisciplinary teams and one of the studies only looked at one cadre (Effken, *et al*.) suggested that future studies look at other providers in the care setting [45].

There was surprising variability across the studies with respect the network metrics calculated and used. Two—centrality (in-degree) and density were included in 4 and 3 of 6 studies. The range of network metrics calculated per study included in our review ranged from 0 to 15 with most calculating 3 or 4. See Table 4 for a breakdown of which studies calculated which metrics.

What methods were used for which types of research questions?

With only six studies meeting our criteria, there are limits to identifying clear patterns in methods used to address types of research questions and study objectives. Table 6 focuses on the link between types of research questions and study methods. Research questions were classified as either descriptive, relational or causal in nature [52]. Half of the studies included more than one type of research question. Those studies that included causal or relational research questions typically involved more robust quantitative analyses. Mixed methods were used in two studies: one only had causal research questions while the other had descriptive and relational research questions. Most study designs were observational and cross-sectional and had descriptive and relational research questions. As more studies are conducted over the coming years, these patterns will likely evolve and become more consistent.

While the focus of our review has been on these two research questions as applied to the six articles that met our search criteria, there are a range of SNA methods and metrics beyond what is discussed here which could have applicability in answering research questions related to health care professional advice networks and performance including, but not limited to block modelling, core-periphery, presence of structural holes and bridges, cohesion, proximity, and prestige/prominence analyses.

Limitations of the review

This review looked at a very specific question and found that few, albeit in recent years a growing number of researchers, have designed studies meeting these criteria. Our definition of performance as being assessed by patient outcomes rather than through proxy interim measures, such as use of evidence-based tools and practices, restricted the studies that met our search criteria. This may have been particularly limiting for studies of community based health care, which often takes the form of counselling whereby certain outcomes like patient satisfaction are more likely to be appropriate study outcomes than patient outcomes. Our definition of professional communication networks excluded studies of provider friendship networks or other types of ties between healthcare workers unless they explicitly captured professional communication. In theory, those networks may have embedded professional advice exchange not captured, analysed or presented in the paper. Another limitation is that we only looked at English language publications. However, looking at other systematic reviews of SNA studies, that is a common limitation.[13, 22, 25, 27-29] For those that included studies in other languages, like Benton, *et al.* which

included Spanish and Portuguese language studies, they found 2 of 43 included studies were non-English and excluded a further 2 for language reasons.[23] Chambers, *et al.* and Flodgren, *et al.* did not impose any language restrictions in their searches, but did not identify studies published outside of English language journals, so this is unlikely to be a major source of bias [5, 26]. We limited our searchers to those studies published from 1990, although given the emphasis on software packages in current SNA studies, it was believed that few studies would have been using relevant methods before 1990 as those software packages did not exist for use on widely accessible platforms.

Another limitation speaks to broader limitations of systematic reviews. The language used for social network analysis is vague and inconsistent, and search strategies were challenging to devise that returned a manageable number of articles to screen yet were broad enough to capture all the ways in which researchers may have described an SNA study.

Conclusion

Five years after the Chambers, *et al*. review, searched for articles, social network analysis methods continue to be underutilized in the health sector, particularly when looking at health care provider communication and performance [5]. There are few studies that do more than describe professional communication networks among healthcare providers, for those that do, only a small subset, six measure performance using patient outcomes. This may be a broader reflection of the challenge in accurately capturing patient outcome data as many studies were excluded for using proxy measures such as patient satisfaction or use of an evidence based practice. While a diverse set of methods were used across the six studies, as more studies are conducted clearer patterns in methods may emerge. The quality of these studies was either acceptable or high; however, the level of sophistication of these studies was relatively low with an emphasis on cross-sectional study designs. This is not an unsurprising finding as the network methods themselves and software tools capable of dynamic and longitudinal network analyses are still developing. As longitudinal SNA analysis methods mature, other study designs and network interventions should become more common. All articles meeting the review criteria were published in the past five years, suggesting that this is a developing area of research.

One pattern that this review highlights is a trend towards looking at multidisciplinary provider networks rather than focusing on one cadre. Other SNA methodological consistencies among these six studies included a preference for calculating specific network metrics: density and centrality. The limited number of articles meeting our search criteria, the glaring lack of any studies in LMIC, non-Western contexts and in non-tertiary settings or community-based settings present clear research opportunities. Once there are more studies published addressing health care provider communication and performance, it may be useful to revisit this analysis and draw conclusions on the SNA methods best placed to answer specific research questions within this space.

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Table 2 Summary of the six studies included in this review

Author(date) Country	Study Objectives Type/number of Health care worker (HCW)	Research questions Patient Outcomes	Study Design Study Findings	Data Collection Method(s) Limitations	Critical Appraisal (0/+/++)
Effken, *et al.* (2011) [45] USA	*Study Objectives:* Identifying nursing unit communication patterns associated with patient safety and quality outcomes	*Research questions:* Can ORA's visualisations be used to identify patient care unit network communication patterns that affect patient safety and quality outcomes? Do unit network characteristics differ by shift? What network characteristics measured by ORA metrics are related to specific safety and quality measures?	*Study Design:* observational; cross-sectional	*Data Collection Method(s):* Organizational network Analysis questionnaire, previously collected survey with patient outcome data	*Critical Appraisal*: ++
	Type/number of HCW: Nursing staff, number not stated	*Patient Outcomes:* Adverse drug events Falls Symptom management difference Symptom management capacity Simple self-care management Complex self-care management	*Study Findings:* Demonstrated utility of ORA software for healthcare research and relationship of nursing unit communication patterns to patient safety and outcomes. Differences between day and night shift communication networks. Found more communication not always associated with better patient outcomes, specifically falls and adverse drug events.	*Limitations:* Small and homogenous sample size; Only nursing staff; Limited to weekday shifts; Some of the patient outcomes (falls and adverse drug events) were infrequent events	

Author(date) Country	Study Objectives Type/number of Health care worker (HCW)	Research questions Patient Outcomes	Study Design Study Findings	Data Collection Method(s) Limitations	Critical Appraisal (0/+/++)
Lindberg, *et al.* (2013) [47] USA	*Study Objectives:* Evaluate how intervention affected adherence to infection prevention protocols, patient outcomes and dialysis center social networks	*Research questions:* Does a package of interventions including membership to a collaborative emphasising positive deviance change HCW collaboration, infection prevention and innovation networks? Do patient outcomes change?	*Study Design:* Experimental pre-post intervention Longitudinal Mixed-methods SNA retrospective	*Data Collection Method(s):* Survey, Focus Group Discussions, Observation, Patient data extraction	*Critical Appraisal:* +
	Type/number of HCW: Multidisciplinary: staff at an outpatient haemodialysis facility. SNA: 51 identified (46 completed each of the 2 surveys 90%)FGD: 16	*Patient Outcomes:* Infection rates in patients	*Study Findings:* There were changes in all 3 networks following the implementation of the package of interventions. For Collaboration: centralization and reach increased, connectivity decreased and no change in inclusion. For bloodstream infection (BSI): prevention reach increased, the others did not change significantly. For Innovation: inclusion and reach increased, reach decreased and centralization did not change. Qualitative data supports the noted changes in network with staff looking to each other for innovations in infection prevention, working more as a cohesive team. Patient outcomes improved, with lower incidence of BSIs, although they were a relatively rare event.	*Limitations:* Results are based on one dialysis centre and may not be generalisable to other centres.SNA was based on a retrospective survey and might have been subject to recall bias. The results of the time series analysis are limited as access-related bloodstream infections (AR-BSIs) are a relatively rare outcome and there were a small number of time points between interventions. Researchers were unable to stratify AR-BSIs by access type before 2009.	

Author(date) Country	Study Objectives Type/number of Health care worker (HCW)	Research questions Patient Outcomes	Study Design Study Findings	Data Collection Method(s) Limitations	Critical Appraisal (0/+/++)
Alexander, *et al.* (2015) [43] USA	*Study Objectives:* To evaluate how differences in IT sophistication in nursing homes impact communication and use of technology and associations with skin care and pressure ulcers	*Research questions:* What communication strategies do nursing home staff use to provide care to residents at risk of skin breakdown and pressure ulcers? What evidence-based pressure ulcer preventions are used by nursing home staff with diverse IT sophistication? What social networks of CNAs enhance or interrupt workflow and have positive or negative effects on nursing work?	*Study Design:* Observational mixed method case studies	*Data Collection Method(s):* For SNA: Observation of communication among HCWs was documented using a structured field note guide	*Critical Appraisal:* +
	Type/number of HCW: Nursing staff. FGD: 21; SNA: Nurses at 2 nursing homes, 1,386 observations (unit of analysis was not based on number of HCWs)	*Patient Outcomes:* Incidence of pressure ulcers	*Study Findings:* High IT sophistication lead to more diverse locations for HCW interactions. Low IT sophistication required more face to face interaction in more centralized locations within the nursing home. Patient outcomes captured were more or less equivalent between the two facilities.	*Limitations:* The study focused on observations only during the day shift. Individual RNs/LPNs and CNAs were not uniquely identified during observations and the analysis lumped them together as RNs/LPNs and CNAs respectively. 2 nursing homes with a specific degree of IT sophistication were compared, rather than following any change due to the introduction of IT sophistication. Confounding variables offer an opportunity for increasing bias in the results. Generalisability may not be appropriate as this study was an in-depth analysis of 2 nursing homes in one state - Missouri.	

Author(date) Country	Study Objectives Type/number of Health care worker (HCW)	Research questions Patient Outcomes	Study Design Study Findings	Data Collection Method(s) Limitations	Critical Appraisal (0/+/++)
Creswick and Westbrook (2015) [44] Australia	*Study Objectives:* Determine if there are network property differences in prescription advice-seeking associated with prescription errors	*Research questions:* 1. Identify and measure from whom hospital clinical staff seek medication advice on a weekly basis 2. Quantify the use of other sources of medication information, assess the difference in medication advice-seeking patterns across professional groups 3. Examine network characteristics in relation to prescribing error rates	*Study Design:* Observational Cross-sectional	*Data Collection Method(s):* Questionnaire for SNA and clinical audit	*Critical Appraisal:* ++
	Type/number of HCW: Multidisciplinary: physicians, nurses and allied health professionals. 101 participants	*Patient Outcomes:* Prescription error rates	*Study Findings*: Limited inter-professional advice seeking overall (particularly between physicians and nurses). Hubs of advice provisions include pharmacists, junior physicians and senior nurses. Senior physicians are not involved in these advice exchange networks. The ward with the stronger (denser) advice seeking network had lower rates of procedural and clinical prescribing errors.	*Limitations:* Limited in scope (only two wards). No psychometric assessments. Networks only examined at one point in time.	

Author(date) Country	Study Objectives Type/number of Health care worker (HCW)	Research questions Patient Outcomes	Study Design Study Findings	Data Collection Method(s) Limitations	Critical Appraisal (0/+/++)
Mundt, *et al.* (2015) [48] USA	*Study Objectives:* To understand what team communication structures, contribute to alcohol-related utilisation of care and medical costs. *Type/number of HCW:* Multidisciplinary: physicians, physician assistants, nurse practitioners, registered nurses, medical assistants, licensed practical nurses, laboratory technicians, radiology technicians, clinic managers, medical receptionists, other patient care staff. 160 HCWs were invited, 155 took part. 31 care teams	*Research questions:* What primary care team communication networks are associated with alcohol-related utilisation of care and medical costs for primary care patients? *Patient Outcomes:* Alcohol-related emergency department visits, Hospital days and associated costs	*Study Design:* Observational, Retrospective *Study Findings:* Teams' variations in communication patterns (face to face and through electronic health record) are associated with statistically significant differences in alcohol-related patient utilisation and medical costs in their patient panels. Excessive alcohol-using patients may fair better if they are cared for by teams with RNs who interact with more team members including LPNs/MAs and by teams whose frequent daily face-to-face communication to the primary care practitioner has been streamlined to a smaller number of team members.	*Data Collection Method(s):* Questionnaire administered in person, electronic health record extractions *Limitations:* Only six practices in limited geography included. No information on content of communication. No information on frequency and quality of alcohol services delivered. Unclear rationale for type of communication method. Increased risk of type I error. Study may underestimate full impact given underreporting of alcohol-related diagnoses in electronic health record.	*Critical Appraisal:* ++

Author(date) Country	Study Objectives Type/number of Health care worker (HCW)	Research questions Patient Outcomes	Study Design Study Findings	Data Collection Method(s) Limitations	Critical Appraisal (0/+/++)
Hossain and Guan (2012) [46] USA	*Study Objectives:* To understand coordination in an emergency department through measures of performance and quality	*Research questions:* Test the following hypotheses: Performance of coordination in the emergency department is influenced by the social network. Performance of coordination in the emergency department is influenced by the centrality of the network. Performance of coordination in the emergency department is influenced by the density of the network. Performance of coordination in the emergency department is influences by the degree of connections in the network.	*Study Design:* Observational Cross-sectional	*Data Collection Method(s):* National Hospital Ambulatory Medical Care Survey (NHAMCS), patient record surveys selected from emergency departments.	*Critical Appraisal:* ++
	Type/number of HCW: Multidisciplinary: emergency department hospital staff. Staff included in patient reports from 359 emergency departments	*Patient Outcomes:* Length of visit, Wait time to see physician, Revisits within 72 hours, Deaths within emergency department, Left before seeing physician.	*Study Findings:* Coordination and the social network are heavily related within the emergency department. Specifically: As emergency department network density increases, number of patients waiting over triage time decreases but doesn't influence average wait times. As degree of connection increases the wait time for patients increases. No evidence of connection between quality of service and death and the social networks. Quality of coordination in emergency department is influenced by centrality of the network. As communication in emergency department increases, the number of patients revisiting decreases.	*Limitations:* NHAMCS dataset is incomplete, contains less than 40 surveys of each emergency department, which is less than the assumed volume of patients in a 3-month period.	

Table 3 Summary of studies' social network analysis methods

Authors	Effken *et al.*	Hossain and Guan	Lindberg *et al.*	Alexander *et al.*	Creswick and Westbrook	Mundt *et al.*
Data Collection Method	Network survey, previously collected survey with patient outcomes	Extraction from National Hospital Ambulatory Medical Care Survey (NHAMCS), patient record surveys selected from emergency departments	Survey, focus group discussions, observation, patient data extraction	Observation, previously collected survey	Network survey and clinical audit	Network survey and electronic health record extractions
Boundary specification method/ sampling (if applicable)	All nursing staff who worked in one of seven patient care units in three magnet hospitals	Emergency departments of 359 hospitals responded to the ambulatory survey section of NHAMCS survey conducted by the CDC	All staff at 21 hemodialysis facilities that form part of the CDC Hemodialysis BSI Prevention Collaborative	Comparative case study of two units within two nursing homes, one with the highest IT sophistication and one with the lowest IT sophistication based on a statewide census in 2007. Nodes were both HCWs and the locations and content of their interactions	All HCWs in two wards	Eight clinics in southern Wisconsin were invited to participate in the study and six agreed. Sites chosen based on consultation with leadership from the healthcare system.
Network category studied 1. Whole, ego or hybrid network 2. Directed or undirected 3. Valued or dichotomous	1. Whole network 2. Directed 3. Valued	1. Whole network 2. Directed 3. Dichotomous	1. Whole network 2. Directed 3. Valued	1. Whole network 2. Directed 3. Valued	1. Whole network 2. Directed 3. Valued	1. Whole network 2. Directed 3. Valued
Response rate	Not stated	N/A as SNA data extracted from surveys on patients	90%	N/A as SNA from observation	90%	97%

Authors	Effken *et al.*	Hossain and Guan	Lindberg *et al.*	Alexander *et al.*	Creswick and Westbrook	Mundt *et al.*
Network metrics used	Clustering Coefficient, Component count strong, component count weak, density, diffusion, fragmentation, hierarchy, isolates, in-degree centrality, out-degree centrality, eigenvector centrality, simmelian ties, betweeness centrality, number of triads, number of cliques	SNA metrics: degree, density, centrality	Connectivity, inclusion, reach and centralization.	None	Density Reciprocity In-degree centrality	In-degree centrality, tie strength
Analyses conducted	Correlations (Spearman Rho) calculated between SNA metrics and patient outcomes	Multiple linear regression, *p* values and *r* values reported	Quantitative: Pearson X^2 and Fisher's exact test, t test. Reported *p* values. Qualitative analysis: reflexive observation and contextual analysis.	Quantitative: Calculated highest and lowest ITS NH from survey data in a earlier study Qualitative: axial coding, themes developed using human factors theory	Chi-squared with *p* values	Linear Modelling (GLMM) and sensitivity analyses.
Software	ORA, Excel	UCINET, SPSS, Excel	Not stated	ORA, Nvivo, Excel	UCINET and Netdraw	UCINET, HLM 7.0
Network Map (Yes/No)	Yes	Yes	Not stated	Yes	Yes	Yes

Authors	Effken *et al.*	Hossain and Guan	Lindberg *et al.*	Alexander *et al.*	Creswick and Westbrook	Mundt *et al.*
Further research	Replicate study, expand to larger, more diverse group of patient care units. Consider shifting to more patient-centric focus, including full team of care providers	Further research needed to verify the relationship suggested by this study between coordination and social network analysis. Survey of emergency departments within Australia for a period of 1year, to allow accurate measurements to be taken and utilised for the study and for verifying the relationship between social networks and coordination in an emergency department.	None stated	To demonstrate how organisation analytics about communication can be used to benchmark evidence-based practices.	Further research on link between medication advice seeking networks and errors, as this study suggests. Also, whether the increased use of electronic medication management systems means that information needs are met through channels other than communication between physicians, nurses and pharmacists, or that information sharing regarding medication issues is reduced and may impact medication safety. Evaluate interventions to engage senior physicians in advice exchange networks. Further health applications of SNA surveys needed to improve validity and reliability of tools.	Longitudinal and experimental studies needed to explore the causal pathways between team communication variables and alcohol-related patient care
Network intervention (yes/no)	No	No	Yes (although intervention not based on baseline network analysis. Rather, it was developed with the intention of changing HCW networks)	No	No	No

Table 5 Analysis of studies' SNA metrics and patient outcome findings

Metric	Study	Patient Outcomes	Association with metric	Overall association
Centrality	Effken *et al.*	Adverse drug events (ADEs)	"Betweenness centrality" positively correlated (rho=.73) with ADEs	Generally, as centrality measures increase, patient outcomes improve, however there were many patient outcomes for which there was no significant association with a centrality measure. Effken exception. Higher betweenness centrality, with potentially more gatekeepers resulted in more ADEs. With symptom management difference the seemingly inconsistent association with centrality could actually point to the importance of small group communication with this outcome measure and that those with more out degree ties are novices seeking advice.
		Falls	Not significant	
		Symptom management difference	"Centrality out degree" negatively correlated (rho= -.79) although eigenvector centrality positively correlated (rho=.69)	
		Symptom management capacity	Not significant	
		Simple self-care management	Not significant	
		Complex self-care management	Not significant	
	Lindberg *et al.*	Access-Related bloodstream infections	Not significant	
	Mundt *et al.*	Alcohol-related emergency department visits	Statistically significant (sig.) GLMM model with only weak "in-degree ties" had positive association (RR 1.23, p<0.01), models with any strong ties had inverse association (RR range 0.8-0.9, p<0.05)	
		Alcohol-related hospitalizations	Sig. GLMM models with groups of HCWs with any weak "in degree ties" had positive association (RR 1.1, p<0.05, RR 1.25, p<0.01), model with groups of HCWs with only strong ties had inverse association (RR .95, p<0.05)	
		Alcohol-related costs per 1000 team patients over 12 months	In an average team size of 19, the addition of a HCW with strong "in degree ties" reduced cost by $1030 (p<0.05), weak ties increased cost by $2922 (p<0.01)	
	Hossain and Guan	Wait time to see physician	Not significant	
		Revisits within 72 h	Not significant	
		Deaths within emergency department	Not significant	
		Left before seeing physician	"network centralization" inversely associated (beta=-0.221, sig.<0.001)	

Table 5 Analysis of studies' SNA metrics and patient outcome findings *(Continued)*

Metric	Study	Patient Outcomes	Association with metric	Overall association
Density	Effken *et al.*	Adverse drug events	Not significant	Density positively associated with improved patient outcomes. However, there were patient outcomes for which there was no significant relationship with density.
		Falls	Not significant	
		Symptom management difference	Positively associated (rho=0.70, p<0.10)	
		Symptom management capacity	Positively associated (rho=0.75, p<0.10)	
		Simple self-care management	Not significant	
		Complex self-care management	Not significant	
	Creswick and Westbrook	Prescription error rates (procedural and clinical)	Inversely associated (Ward A error rates 5.46 and 1.81 with density 12% vs Ward B error rates 1.53 and 0.63 with density 7%)	
	Hossain and Guan	Wait time to see physician	Inversely associated (beta=-0.107) for waiting "overestimated triage time" but not significant for "waiting above average"	
		Revisits within 72 h	inversely associated (beta= -0.159, sig.= 0.003)	
		Deaths within emergency department	Not significant	
		Left before seeing physician	Inversely associated (beta=-0.273, sig. <0.001)	

Table 6 Analysis of studies' research questions and study methods used

Study	Objectives/Research questions	Research question categories	Methods
Effken, *et al*	Identify nursing unit communication patterns associated with patient safety and quality outcomes 1. Can ORA's visualizations be used to identify patient care unit network communication patterns that affect patient safety and quality outcomes? 2. Do unit network characteristics differ by shift? 3. What network characteristics measured by ORA metrics are related to specific safety and quality measures?	1. Descriptive 2. Descriptive 3. Relational	Design: observational, cross-sectional Data collection: Organizational Network Analysis questionnaire, patient outcome survey Analyses: Correlations (Spearman Rho) calculated between SNA metrics and patient outcomes
Lindberg, *et al*	Determine if intervention changed adherence to infection prevention protocols, patient outcomes and dialysis center social networks 1. Does a package of interventions including membership to a collaborative emphasising positive deviance change HCW collaboration, infection prevention and innovation networks? 2. Do patient outcomes change?	1. Causal 2. Causal	Design: experimental, longitudinal, mixed methods, pre-post intervention Data collection: Survey, FGD, Observation, Patient data extraction Analyses: Quantitative: Pearson X^2 and Fisher's exact test, t test. Reported *p* values. Qualitative analysis: reflexive observation and contextual analysis.

Study	Objectives/Research questions	Research question categories	Methods
Alexander, *et al*	Evaluate how differences in IT sophistication in nursing homes impact communication and use of technology related to skin care and pressure ulcers. 1. What communication strategies do nursing home staff use to provide care to residents at risk of skin breakdown and pressure ulcers? 2. What evidence-based pressure ulcer preventions are used by nursing home staff with diverse IT sophistication? 3. What social networks of CNAs enhance or interrupt workflow and have positive or negative effects on nursing work?	1. Descriptive 2. Descriptive 3. Relational	Design: observational mixed methods, case studies Data collection: Observation, previously collected survey Analysis: Quantitative: Calculated highest and lowest ITS NH and patient outcomes from survey data in a earlier study Qualitative: Axial coding, themes developed using human factors theory
Creswick and Westbrook	Determine if there are network property differences in prescription advice seeking associated with prescription errors 1. Identify and measure from whom hospital clinical staff seek medication advice on a weekly basis 2. Quantify the use of other sources of medication information, assess the difference in medication advice-seeking patterns across professional groups 3. Examine network characteristics in relation to prescribing error rates	1. Descriptive 2. Descriptive 3. Relational	Design: observational, cross-sectional Data collection: Network survey and clinical audit Analyses: Chi-squared with p values

Study	Objectives/Research questions	Research question categories	Methods
Mundt, *et al*	To understand what team communication structures contribute to alcohol-related utilisation of care and medical costs. 1. What primary care team communication networks are associated with alcohol-related utilisation of care and medical costs for primary care patients?	1. Relational	Design: observational, cross-sectional, retrospective Data collection: Network Survey, Electronic health record extractions Analyses: Linear Modelling (GLMM) and sensitivity analyses.
Hossain and Guan	To understand coordination in an emergency department through measures of performance and quality 1. Is performance of coordination in the ED influenced by the social network? 2. Is performance of coordination in the ED influenced by the centrality of the network? 3. Is performance of coordination in the ED influenced by the density of the network? 4. Is performance of coordination in the ED influenced by the degree of connections in the network?	1. Causal 2. Causal 3. Causal 4. Causal	Design: observational, cross-sectional Data collection: survey extraction Analyses: Multiple linear regression, p values and r values reported

7. Ethiopia Network Study Paper

London School of Hygiene & Tropical Medicine
Keppel Street, London WC1E 7HT
www.lshtm.ac.uk

Registry
T: +44(0)20 7299 4646
F: +44(0)20 7299 4656
E: registry@lshtm.ac.uk

LONDON SCHOOL of HYGIENE &TROPICAL MEDICINE

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SECTION A – Student Details

Student	Kate Sabot
Principal Supervisor	Joanna Schellenberg
Thesis Title	The use of social network analysis to study health care provider advice and performance

If the Research Paper has previously been published please complete Section B, if not please move to Section C

SECTION B – Paper already published

Where was the work published?			
When was the work published?			
If the work was published prior to registration for your research degree, give a brief rationale for its inclusion			
Have you retained the copyright for the work?*	Choose an item.	Was the work subject to academic peer review?	Choose an item.

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SECTION C – Prepared for publication, but not yet published

Where is the work intended to be published?	BMC Health Systems Research
Please list the paper's authors in the intended authorship order:	Kate Sabot, Karl Blanchet, Della Berhanu, Neil Spicer, Joanna Schellenberg
Stage of publication	**Submitted**

SECTION D – Multi-authored work

For multi-authored work, give full details of your role in the research included in the paper and in the preparation of the paper. (Attach a further sheet if necessary)	I designed the study, with input from my supervisor and committee. I wrote the study protocol, managed ethical clearance, engaged the FMOH for input, conducted pre-testing, trained enumerators, supervised initial data collection, reviewed expanded field notes during qualitative data collection, double entered and analysed data. I was the primary

	author of the manuscript, integrating co-author feedback through the various drafts .

Student Signature: [redacted] **Date:** 24 October 2017

Supervisor Signature: [redacted] **Date:** 24 October 2017

7.2 Professional advice for primary health care workers in Ethiopia: a social network analysis

Authors:

Kate Sabot[1 2*] kate.sabot@lshtm.ac.uk

Karl Blanchet [3] karl.blanchet@lshtm.ac.uk

Della Berhanu [1 2] della.berhanu@lshtm.ac.uk

Neil Spicer[3] neil.spicer@lshtm.ac.uk

Joanna Schellenberg [1 2] joanna.schellenberg@lshtm.ac.uk

[1]The Centre for Maternal, Adolescent, Reproductive and Child Health (MARCH), London School of Hygiene and Tropical Medicine

[2]Department of Disease Control, Faculty of Infectious and Tropical Diseases, London School of Hygiene and Tropical Medicine

[3]Department of Global Health, Faculty of Public Health and Policy, London School of Hygiene and Tropical Medicine

*Corresponding author kate.sabot@lshtm.ac.uk

Institutional address:

London School of Hygiene and Tropical Medicine, Keppel Street, London WC1E 7HT, UK

Abstract

Background: In an era of increasingly competitive funding, governments and donors will be looking for creative ways to extend and maximise resources. One such means can include building upon professional advice networks to more efficiently introduce, scale up, or change programmes and healthcare provider practices. This cross-sectional, mixed-methods, observational study compared professional advice networks of healthcare workers in eight primary health care units across four regions of Ethiopia. Primary health care units include a health centre and typically five satellite health posts.

Methods: 160 staff at eight primary health care units were interviewed using a structured tool. Quantitative data captured the frequency of healthcare worker advice seeking and giving on providing antenatal, childbirth, postnatal and newborn care. Network and actor-level metrics were calculated including density (ratio of ties between actors to all possible ties), centrality (number of ties incident to an actor), distance (average number of steps between actors) and size (number of actors within the network). Following quantitative network analyses, 20 qualitative interviews were conducted with network study participants from four primary health care units. Qualitative interviews aimed to interpret and explain network properties observed. Data were entered, analysed or visualised using Excel 6.0, UCINET 6.0, Netdraw and MaxQDA10 software packages.

Results: The following average network level metrics were observed: density .26 (SD.11), degree centrality .45 (SD.08), distance 1.94 (SD.26), number of ties 95.63 (SD 35.46), size of network 20.25 (SD 3.65). Advice networks for antenatal or maternity care were more utilised than advice networks for post-natal or newborn care. Advice networks were typically limited to primary health care unit staff, but not necessarily to supervisors. In seeking advice, a colleague's level of training and knowledge were valued over experience. Advice exchange primarily took place in person or over the phone rather than over email or online fora. There were few barriers to seeking advice.

Conclusion: Informal, inter-and intra-cadre advice networks existed. Fellow primary health care unit staff were preferred, particularly midwives, but networks were not limited to the primary health care unit. Additional research is needed to associate network properties with outcomes and pilot network interventions with central actors.

Keywords

Social Network Analysis; healthcare workers; professional advice; advice networks; maternal and newborn health; Ethiopia; health extension workers

Background

Social Network Analysis (SNA) is a research approach consisting of a set of theories and methods for mapping communication, information flow and relationships between individuals or groups. SNA has been applied in a wide range of social and physical science fields [1-3]. While some of the seminal SNA articles are health related [4], and there is a growing body of research on health professional advice networks [5-7], little is known about networks among frontline health workers in low and middle-income countries [8-10].

Over the last ten years, Ethiopia has expanded its health work force considerably, through the introduction of a community-based cadre, health extension workers (HEWs). Yet skilled human resources for health remain a constraint in the equitable availability, accessibility and delivery of healthcare [11]. Ethiopia's impressive gains in achieving child health targets, with respect to the Millennium Development Goals, have been attributed in part to the Health Extension Programme [12, 13]. Recent data suggest maternal and newborn mortality rates (NMR) are starting to improve after a period of stagnation. Although the 2016 Demographic Health Survey (DHS) indicated progress with a promising drop to 29 from 37 neonatal deaths per 1,000 live births, deaths in the first month of life still account for a large proportion of overall child mortality[14]. Similarly, maternal mortality stagnated with no improvement between the 2005 and 2011 DHS reports [15]. The most recent DHS shows a decline to 442 from 676 deaths per 100,000 live births in 2016 [14]. These gains in health outcomes are encouraging and may be attributable to the health systems changes described above. Nevertheless, maternal and neonatal mortality rates are unacceptably high and well away from the Sustainable Development Goals (SDGs) targets for 2030. Ethiopia's previous maternal and newborn health targets were relative to their levels in 1990; the new SDG set absolute targets for all countries to meet by 2030 [16, 17]. To achieve these SDGs, Ethiopia must reduce neonatal deaths from 29 to 12 per 1000 live births and maternal deaths from 442 to 70 per 100,000 live births in an environment of increasingly constrained health resources [14, 17, 18].

Communication among healthcare workers could be a critical contextual factor affecting whether or not mothers and newborns receive life-saving interventions. Understanding professional advice networks provides foundational information for designing network-based interventions to improve health outcomes [19]. This study aimed to contribute to the understanding of professional advice networks of frontline health workers in Ethiopia. Specifically, this research explored the properties of professional advice networks; the content of advice exchange, the context in which advice exchange took place; who participated in advice exchange; and the extent to which advice networks met healthcare worker needs. Our study focused on healthcare workers implementing a government program known as Community

Based Newborn Care (CBNC), designed to address gaps in maternal and newborn care. This subset of healthcare workers were chosen as they were implementing a new health program, thus creating the possibility of advice exchange related to these services.

Ethiopian Health Delivery Context

Ethiopia has a decentralised, structured model for the delivery of healthcare with the Federal Ministry of Health as the policy-setting body. The four tiered-system provides services at specialised, zonal and district hospitals and primary health care units (PHCUs) [11]. PHCUs serve approximately 25,000 people through a referral health centre and five health posts. In 2003, Ethiopia introduced the Health Extension Program (HEP), an ambitious plan to improve delivery of primary health care through the introduction of over 30,000 Health Extension Workers [11]. HEWs are government salaried women, 18 years or older, who completed 10^{th} grade schooling [20]. They work in their kebele, the Ethiopian equivalent of a village, in pairs at a health post after receiving a one-year training to deliver a package of 17 essential preventative and curative health services [11, 21]. HEWs have a formal reporting system whereby within a PHCU all HEWs report to a single designated staff member at the health centre. HEWs are supported by a network of volunteers. Studies of HEWs have found their full potential unrealised, calling for additional training and resources for them to maximise their impact on maternal and newborn health [11, 22-25].

In 2013, the Ethiopian government launched CBNC to build on the HEP platform [26]. CBNC aims to improve newborn health outcomes using a framework of “four Cs” and 9 components, see **Additional File 1** [27]. CBNC depends on HEWs working with Woman Health Development Teams to identify and refer sick newborns, and when referral is not possible, treat in the community. Health systems are social systems, in Ethiopia linking the community to health services relies on the professional relationships of HEWs [28].

Social Network Analysis

A social network is a set of socially relevant ‘nodes’ representing actors - either individuals or organisations - connected by one or more relations [29]. In SNA, the patterns in the relationships between actors are studied. This is distinct from much quantitative public health research, which looks at the relationship between variables and outcomes of interest [30, 31]. While there is a longstanding history of social network analysis in health,[3] recent reviews suggest that the potential has yet to be realised [10]. Much of the work to date focused on spread of disease, diffusion of ideas, impact of social networks on individual health behaviour and inter-organisational structure of health systems [32]. There was little known about professional communication among health professionals [32]. Research on health care worker advice

networks has mostly been descriptive and not related to the provision of primary health care [7, 33-35].

Applications of SNA methods in the community-based health contexts of low- and middle-income countries (LMIC) are similarly limited [36].To date there have been few social network analysis studies in Ethiopia [37, 38, 39, 40, 41] and none in primary health care settings.

Relational data can be collected through questionnaires, interviews, observations and analysis of existing records, diaries or other methods [42]. These data are then populated into matrices, or tables and uploaded into software designed to generate visualisations, knowns as sociograms, and calculate network properties. In SNA, visualising data is both a means of presenting findings as well as a tool for identifying patterns and generating findings. The most basic sociograms depict actors as points with connecting lines representing relationships. It is possible to overlay additional information ("attributes") to qualify the actors or their relationships. These "attributes" can be displayed by changing the colour, size or shape of the actor. The strength of the relationship can be represented by adjusting the thickness of lines connecting actors [43].

SNA studies are characterised by whether the network is directed or undirected, valued or unvalued, and by how the boundaries are defined.[42] Directed networks capture if the relationship is one-way, where one actor initiates and another receives or two-way where both initiate and receive. In contrast, in undirected networks, the relationship either exists or does not exist. Valued networks quantify the strength of the relationship between actors [44]. Network boundaries can be specified either through what is known as a 'realist approach' whereby study participants define their own network boundaries or through a 'nominalist approach', which uses formal criteria to determine the network or a hybrid combining the two[45].

The overall objective of this study was to contribute to our understanding of professional advice networks of Primary Health Care Unit staff in rural Ethiopia.

Methodology

Aims

This research aimed to describe the properties of professional advice networks, the content of advice exchange, the context in which advice exchange took place and the extent to which the existing advice networks met healthcare worker needs.

Study design

This was an observational, cross-sectional network study. There were two stages of data collection: (i) a structured network survey, followed by (ii) semi-structured qualitative

interviews. The structured network survey captured valued, directed networks using a roster of PHCU staff from our selected PHCUs, but allowed for respondents to nominate, or name other "off-roster" healthcare professionals as either having provided or sought advice for each of the advice networks of interest. This design was chosen because the research interest is both in describing the advice networks among PHCU staff and also in knowing if advice networks extended to professionals beyond the primary health care unit (such as to peers from past posts or instructors or mentors). It was directed and valued, with data such as who provided or sought advice from whom, both within the PHCU and beyond it, and the frequency of their interaction were documented.

Sampling

STAGE I

PHCUs in zones implementing CBNC formed the sampling pool. Two PHCUs per agrarian region (Amhara, Southern Nations and National People, Oromia and Tigray) were purposively selected for diversity with regard to number of health posts, number of healthcare workers and coverage of key maternal and newborn health services.

STAGE II

Following analysis of network data, semi-structured qualitative interviews were conducted with twenty network study participants to explore and gain an in-depth understanding of patterns emerging from the quantitative analysis. PHCUs and participants were purposively selected, five from each of the four selected PHCUs (one PHCU per region), to capture the range of PHCU network properties (densest networks, individuals with highest eigenvector centrality, least off-roster advice exchange, least ties and highest distance). Individuals were selected to include the breath of cadres, and network characteristics. For example, the HEW with the most ties and the one with the least were included for each PHCU. Interviewed subjects included three health officers, three midwives, five nurses and nine HEWs across four PHCUs.

Tool Design/Testing

STAGE I

Preliminary interviews to inform study design took place in 2013, a network tool was pre-tested in April 2015 and again in August 2015, translated and back translated, revised and field tested in November 2015. It captured the frequency of seeking and giving advice among PHCU staff using a roster. The following respondent characteristics, also known as attribute data were also captured: gender, age, cadre (health officer, midwife, health extension worker and all categories of nurses) and total years of experience.

STAGE II

The semi-structured interview guide was initially developed in August 2015, revised following analysis of quantitative data and further refined after the initial qualitative interviews. Themes explored included who is sought for advice and why, reasons for advice exchange, if advice needs are being met, and barriers to advice exchange.

Data Collection

STAGE I

Data were collected by two research teams after a three-day training. The first PHCU's data were collected together by the two research teams with the lead researcher overseeing and managing the daily review sessions. Research teams consisted of two interviewers and one supervisor who were native speakers of the languages involved (Amharic, Oromifya or Tigrinya). Data were collected over a period of 3 weeks in November and December 2015.

STAGE II

Semi-structured interviews were conducted in June and August 2016 by two teams of trained qualitative researchers. Teams consisted of an interviewer and an interpreter. Interviews were conducted in private spaces in a mix of English, Amharic, Oromifya or Tigrinia. Interviews were sound recorded and detailed notes were expanded immediately following interviews.

Data Management

STAGE I

Network survey data were collected using paper forms. All rosters and 160 network questionnaires were double entered into Excel [46]. Discrepancies were reviewed and reconciled. Data were imported into UCINET 6.0 for analysis [47].

Each PHCU had seven network matrices (all advice exchange, all advice giving, all advice seeking, all ANC advice exchange, all maternity advice exchange, all PNC advice exchange and all newborn care advice exchange) and one table of attribute data.

STAGE II

Qualitative data included 20 sets of expanded field notes written in English. Sound recordings were used to spot check the translation and expanded field notes. These were imported into MAXQDA 10.0 for analysis.

Quality control measures

STAGE I

The supervisor oversaw quality control measures including reviewing the consistency of the rosters, labelling the data collection tools with the correct unique identifier, managing daily review meetings with the data collection team and repeating two interviews per PHCU (approximately 10% of the data). Before moving on to another PHCU, supervisors compared repeat interview responses to the original, and made a subjective assessment of consistency. If there was a problem, they were to engage the study manager to discuss whether further interviews should be repeated. To maintain privacy interviews were conducted in private.

Stage II

Expanded field notes were reviewed by the lead author. Guidance was provided on probing and shared with the other research team. Research team deployment was staggered so that the learning from the first few interviews benefited both teams. Interviews were recorded to encourage accurate note-taking as notes could be compared to recordings.

Data Analysis

STAGE I

For each PHCU, a valued adjacency matrix was prepared in Excel for each of the seven networks. Data were imported into UCINET and dichotomised for the calculation of network and actor-level metrics and then imported into Netdraw for visualisations. Additional networks were created by collapsing data captured into themes: all ties, all advice seeking and all advice giving. See **Additional File 2** for definitions of network metrics and their calculations [48].

STAGE II

Data were coded based on inductive and deductive approaches, building from grounded theory, but more applied, focusing less on theory development [49, 50]. An initial coding tree, with code definitions based on review of literature, understanding of the subject area and initial readings of the expanded field notes was applied to a subset of interviews, reviewed, revised and then reapplied. Coded text fragments were reviewed by segment and intersections of codes were

reviewed. Codes were then grouped by respondent cadre to analyse whether patterns emerged by cadre.

Results

Network survey

The eight PHCUs each consisted of one health centre and an average of 4.38 Health posts (SD 1.51) (**Table 1**). Approximately two thirds of the 160 participants were female, with health officers disproportionately male (88%), and midwives disproportionately female (81%) (**Table 2**). The average number of years of experience was 3.6, with 2.5 years at their current post. HEWs on average had the longest total experience and most years at their current post. Overall, 46% were trained or orientated in CBNC programme. All HEWs should be trained in CBNC and from this sample of 160, 78% reported being trained.

Network metrics

Across all networks and all PHCUs the following average network level metrics were observed: density .26 (SD.11), degree centrality .45 (SD.08), distance 1.94 (SD.26), number of ties 95.63 (SD 35.46), size of network 20.25 (SD 3.65) **Table 3** presents the network level statistics by network metric, allowing easy comparison of each network metric across networks and PHCUs. **Additional File 3** presents the same data, grouped by PHCU providing an overview of each PHCU by network type. Patterns emerge with typically ANC and maternity advice networks being denser and having more ties than PNC and Newborn care advice networks. Half of the PHCUs had this same pattern across the networks with degree centrality. There were some exceptions: for PHCU E and F, ANC advice exchange was noticeably denser, however maternity, PNC and newborn care advice exchange networks had similar density. The other clear pattern was that certain PHCUs had more advice exchanging than others (PHCUs E and F had many more ties versus PHCUs A and B).

Actor-level network metrics

In addition to calculating network level properties, actor-level metrics were calculated and the cadre of the actor with the highest value is reported in **Table 4** for each of the networks. Midwives were far more likely to be the actor with the highest in-degree centrality, meaning the most people within the PHCU came to them for advice. This is highlighted in **Additional File 4** and is true for all subject areas, although they were as equally sought as nurses for advice related to providing newborn care.

Visualisations

Each PHCU had their networks visualised both with dichotomised data, which facilitated aggregating the ties across networks, and valued data, which added a layer of understanding related to the frequency of interactions. To illustrate the variability within a PHCU across these networks, PHCU H was selected. **Figure 1** visualises four dichotomised networks with advice seeking and giving for each care area aggregated into one. These sociograms show more ties and fewer isolates for ANC and maternity advice networks relative to PNC and newborn care advice networks.

Valued data were visualised in the same way (with respect to the node attribute data) as for the other sociograms with the exception that the line widths reflect the frequency of interaction (thicker lines reflecting greater frequency ranging from daily to yearly). PHCU A's PNC advice seeking and advice giving sociograms were selected to illustrate in **Figure 2** how there seems to be more advice seeking than advice giving.

To show the variability across the PHCUs for a given type of network maternity advice seeking was selected to show across all 8 PHCUs in **Figure 3-4**. For all of these graphs midwives play a central role, as expected, despite some variability. In **Figure 3,** PHCU D has only advice exchange happening at the HC with the exception of one HEW engaged, whereas in **Figure 4**, PHCU F has many HEWs engaged frequently with HC staff and even some HEWs seeking advice from each other. The intra and intercadre advice exchange depicted by PHCU F was more typical of the findings across PHCUs and topics for advice exchange. The data on formal supervisory structures were available only from a subset of those PHCUs that were selected for the qualitative inquiry. Due to staff turnover, only one could be analysed. This example revealed that advice exchange occurred outside of formal supervisory structures. This confirmed what was observed across other PHCUs, a willingness to engage in informal advice exchange outside of formal supervisory structures. However, an important caveat to this observation is that the qualitative inquiry did not specifically ask participants about the role of formal supervision in their advice exchanges. If present, it should have been mentioned as there were questions around the context of advice exchange, but it remains a possibility that this finding is an artefact of data collection.

Off roster advice seeking

Of the four cadres of healthcare workers, health officers reported the fewest number of individuals they either sought or gave advice to who were not working within their PHCU. However, after adjusting for the different number of HCWs per cadre those distinctions largely disappear. For these HCWs more advice is sought off roster than they are giving to those outside

of the PHCU. This is particularly the case for Health officers and HEWs. By far the most off roster advice exchange occurred for nurses and HEWs seeking advice regarding providing ANC.

Qualitative findings

Who is sought for advice and why?

Reasons for going to a specific person for advice were typically because of that specific person's training and knowledge, less so because of their years of experience. One healthcare worker noted that because of their training in integrated community case management, PHCU colleagues seek their guidance. Some respondents said that they relied on formal supervisory structures, however they appeared relatively infrequent with most people describing qualities of the individuals' knowledge and skills dictating their advice seeking behaviour rather than just formal structures. The examples of consulting supervisors related to situations where they "had some fear or discomfort with the situation and didn't want to take accountability for something going wrong." [Health officer, Tigray] Personality or level of comfort with the person was mentioned as a secondary factor that contributed to who was approached for advice.

In general, current PHCU colleagues were sought for advice, however if they were not available, former classmates and colleagues were the most common individuals sought for advice. For example, one respondent said he'd first go to experienced people in his PHCU, but if they are unable to give advice he would:

> "call some peers, people who [I] went to school with and grew up with, working in other HCs or hospitals who have several years of experience, or even professors to ask for advice in complicated cases." [Health Officer, Amhara]

This was consistent across cadres: health officers, nurses and HEWs for both routine and urgent questions. A nurse in Tigray described a case of postpartum haemorrhage when his supervisor was away at a training, so he had called a midwife he had previously worked with who was now at a different health centre. Several people within this PHCU mentioned seeking advice from this same midwife who had been transferred.

The furthest afield anyone mentioned seeking advice from was from a friend in Addis Ababa because colleagues within the PHCU did not know how to handle the situation. Only one person mentioned seeking advice from someone outside of the PHCU because of not being comfortable asking for a colleague's advice. This does not appear to be a widespread concern for most healthcare workers.

Reasons for advice exchange

According to our respondents, the range of advice given on providing ANC care included many topics already covered in their training. One nurse explained that they need repetition because

learning the content theoretically is so different from doing it practically. This was also the case for advice exchange around other service delivery areas.

> "While the integrated community case management manual is very clear it seems that [the HEW I was advising] lacked confidence and contacted me at the health centre for reassurance." [Nurse, Tigray]

While there are examples of advice being sought for providing antenatal care, it is noteworthy that many respondents said they felt comfortable providing ANC and believed they did not need advice. Several healthcare workers mentioned fearing deliveries and that those with less experience sought those with more for reassurance and guidance. A HEW described seeking advice from another HEW because she had referred more women to the health centre for delivery and she wondered what methods she was using that might be helpful in her own work.

Are advice needs being met?

All interviewees indicated that they had always been able to have their specific questions answered when seeking advice. Interviewers probed further, asking if there were ever situations in which they were unable to have their questions answered, and heard adamant statements from several respondents: "how would I treat them if I [still] needed advice?" [HEW, Amhara] and "[I] will not let uncertainties rest until [I] get [my] questions answered." [HEW, Tigray]

No interviewees said they were unable to get the advice they needed, although some described asking more than one person or consulting other resources. This could reflect a response bias, an unwillingness to admit to providing care while having questions about providing that care. Or it could be that when they had a clear question they could generally find an answer. However, they only asked when they were aware that they did not know something. While their specific questions were addressed, many described a desire for additional training, because as one respondent said, "I will benefit from additional information I am not aware of" [Midwife, Oromia]

Barriers to advice exchange

Many of the HEWs said that they do not deliver babies, although as the closest HCWs to the community they are often involved in referral to the health centre. Some HEWs said they are not involved in postnatal care, although others said they are involved just for identifying dangers signs and referral.[6] When asked why people do not seek advice from her, a HEW said "the HC

[6] This is unusual. Postnatal care is explicitly part of the HEW package of services. However, they may have interpreted "care" to mean providing clinical care, in which case they refer women to health centres.

staff don't ask because they are at a higher level of knowledge, education and training than me and that they would ask each other. They wouldn't think to ask a HEW." [HEW, Amhara]

Respondents commented on the logistical constraints in seeking advice. The poor mobile phone network in some rural areas was mentioned as a barrier, particularly in one PHCU's catchment area, which had only gained network access within the last 8 months. "it [the mobile network] had affected it [advice seeking] before and I remedied this by handling the case to the best of [my] knowledge and asking later to clarify what [I] had done."[Health Officer, Amhara]

Respondents commented that workload sometimes interfered with seeking advice for non-urgent cases. Advice exchange for these non-urgent situations typically happened in person in either at ad-hoc or routine meetings. If urgent, [from respondent's perspective] mobile phones were used, particularly for HCWs seeking advice from more skilled providers at the health centre or woreda.

> "[I] usually ask for advice by phone, especially in the case of emergencies and this advice seeking comes whenever a difficult case arises, once or twice a month. There is nothing stopping [me] from asking for advice as long as the phone networks are working. The network rarely fails around the HC so this is not a big hurdle" [Health Officer, Tigray].

One HEW described her fellow HEW as being "intimidated easily to ask questions, so [I] served as a conduit." [HEW, Amhara] Another said that "If I do not know the answer, I would call someone who is not here, does not work in this place." [Midwife, Oromia] These were the only examples given even with probing with hypothetical reasons for why someone might not feel comfortable seeking advice from their colleagues within the PHCU. Another mentioned language as a possible barrier and that they "could access advice more easily" if rather than speaking in Amharic, they spoke in a local language as "this would avoid missing out on any information."

Discussion

Professional advice networks present an opportunity to more effectively change health provider practice than mere training as health care workers are more likely to be convinced by trusted colleagues. This is particularly relevant in resource constrained settings where funding for and feasibility of training everyone does not exist. This study explores existing advice networks in the context of a new program introduction to learn about these networks and see if there may be potential for harnessing them for future program needs.

There are no standards, norms or expectations for appropriate frequency of advice exchange among health care workers in Ethiopia or elsewhere. Presumably most healthcare workers

should have some advice needs or if not, should be the source of advice for their colleagues, particularly in the context of a new programme being introduced for which not all have been trained. Further complicating interpreting these data is that network scientists debate what network properties constitute a "healthy network" [5].

There were no previous studies of PHCU healthcare worker professional advice networks that documented network properties. Neither were there previous studies of the same healthcare professionals comparing their professional advice exchange networks for ANC, maternity, PNC or newborn care provision. Therefore, this study contributes a foundation which future studies can use to compare their findings.

The advice networks observed had few isolates with limited distance between actors. Five PHCUs had low density and high centrality. There is diversity across the PHCUs in terms of network properties, with variability across all metrics. While some PHCUs fit a pattern whereby there are more ties for ANC and MAT advice networks, other network properties and other PHCUs were more nuanced.

Of note is the willingness of healthcare workers to seek advice and the lack of rigid adherence to the supervisory structure. Given the Ethiopian healthcare delivery context is very hierarchical the existence of informal advice networks is a noteworthy finding. Similarly, a study of Dutch nurses in a long-term care facility found advice networks to be non-hierarchical, although they only looked within one cadre[54]. In studies of inter-professional communication hierarchy is common [7, 34, 55-58].That said, the reliance on informal advice networks may be a product of the frequency of supportive supervision visits and review meetings falling short of standards.

Advice exchange varied by cadre, but universally there was more advice exchanging between cadres than within cadres. This runs counter to what has been found in some western contexts, where professional homophily runs high and advice is primarily sought within a cadre [7, 34, 51]. The direction was typically from the cadre with less training to that with more, with midwives being more engaged for maternity care advice and health officers more for newborn care advice needs. It is important to note that there is specialisation and division of labour within the health centre and between different cadres which could explain some of the patterns observed in the advice seeking. While HEWs say they are not sought by other cadres for advice because of knowledge differentials, the subtext could very well be that a HEW's advice is not sought by other cadres because of power and hierarchy. Advice exchanged between cadres often took place over mobile phones if it was urgent. If it was not urgent, they would wait for supervisory visits or routine meetings. This preference for informal, in person communication is consistent with findings among other, albeit western healthcare contexts [51, 52].

It is a significant finding that the advice networks are largely meeting the advice needs of healthcare workers. Barriers to advice exchange included mobile phone networks and knowing when to ask for advice. Advice needs are being met only in those situations where healthcare workers know what they do not know and seek advice. While a preference was expressed for in person communication, in spite of intention for those to happen regularly, evaluations of HEP note that routine PHCU meetings and supportive supervision fall short of standards [25]. The lack of regular supportive supervision may also account for why these supervisors were not featured more prominently in these advice networks.

Professional advice networks of PHCU staff prioritise proximity, but are not restricted to it. This is relevant both within the PHCU and to those working outside the PHCU. Another study in Italy found geographic distance a factor in physician advice networks [53]. The individuals who were not PHCU staff but were sought for advice ranged from peers from training programs, former colleagues who have since been transferred to those working in nearby PHCUs or hospitals. Typically, they were engaged only if colleagues within the PHCU were unavailable or in one case could not answer the question.

This study shows the value of combining quantitative network methods with qualitative inquiry. This is an approach that more network studies may consider applying should their research objectives include understanding the context surrounding network ties. Such complementary methods could strengthen proposed role of SNA in program implementation [5].

There is a need for further research to understand why there is more advice exchanging around providing antenatal and childbirth care than providing postnatal and newborn care. The aim is to be able to answer the following questions: is this pattern a reflection of true information needs, a product of more patients engaging with the health system at those earlier time points in the “year of the birth”, or a reflect of knowledge gaps in providing postnatal and newborn care sufficient enough for providers not to be able to identify their knowledge limitations. Answering these questions will help identify the appropriate policy response. This could be additional pre-service training on PNC and newborn care such that once in the field healthcare workers are primed to “know what they don’t know.”

This study’s findings, while foundational, could have relevant policy implications for the Ethiopian Federal Ministry of Health and other LMIC contexts. Language was mentioned as a barrier in some advice exchange and some HCW described relying on guidelines and reference materials, if these materials could be available in local languages this would be an easy-to-implement “quick win”. These findings suggest that health care workers value training and knowledge over years of experience when seeking advice. This is something that is worth

exploring further as a policy maker. It may be possible to achieve better outcomes through focusing training on specific individuals within a PHCU whose primary role could be sharing knowledge. Additional research would be needed to test such a concept and see if this targeted training approach yields at least equivalent learning across PHCU staff and patient outcomes.

Additionally, these findings point towards the potential of cadre-based targeted in-service trainings with more central figures within informal advice networks. Further studies, building on what has been done elsewhere exploring the value of network-based training models [59] would be needed to pilot both the feasibility and measure the impact of such an approach to ensure the intervention is scalable and that equivalent outcomes are achieved.

Strengthening supervisory structures may enable them to be more commonly used fora for advice exchange. Health centre staff were noticeably transient relative to HEWs, this may affect advice networks. Further research is needed to understand the directionality of this affect and the policy implications.

Limitations

Approximately eight months passed between the collection of the quantitative data and the collection of the qualitative data. Recall bias may have compromised data quality, but this should be minimal given that there were queries about hypothetical situations and the most recent example of advice exchange. The qualitative data are not explicitly linked to the quantitative network data as the time periods of reflection are inherently different and staff changes were noted in all four of the PHCUs included in the follow up qualitative interviews. While there were anticipated advantages to analysing the quantitative network data and using that data to select participants for the qualitative study, future mixed methods network studies may opt to conduct the qualitative interviews in parallel with the network surveys to eliminate the temporal disconnect.

While effort was made to limit misunderstandings around the type of communication of interest through use of a scripted description to clarify and standardise meaning of “advice seeking and advice giving”, it remains possible that study respondents did not have a common understanding of these concepts. While the study was conducted in three regional languages- Amharic, Tigrinia and Oromifa, it is possible that some participants may have been interviewed in a non-native language.

Conclusions

This exploratory study provides foundational information regarding professional advice networks of primary health care unit health care workers in Ethiopia. This study establishes that

primary health care unit staff involved in delivery of maternal and newborn health services have informal advice networks outside of supervisory structures. Advice exchanges occurred between cadres and used both face to face meetings and mobile phones to exchange advice. More research is needed to understand if the patterns in advice exchange across ANC, maternity, PNC and newborn care accurately reflected advice needs or if they reflected a bias towards antenatal and maternity care knowledge and thus individuals being better placed to self-identify knowledge gaps in those areas. Fellow PHCU staff were prioritised but networks were not limited to those within their geographic area. Policy implications include focusing future training on cadres more central in advice networks, such as midwives for antenatal, maternity and postnatal care and nurses or health officers for newborn care. One possibility could be training an individual or two per PHCU to be the knowledge sharing focal persons, who attend trainings and are responsible for sharing learnings. Another could be cadre-based in service trainings with the same mandate for sharing learnings. Further studies would be needed to pilot such approaches to ensure achievement of equivalent learning and patient outcomes. A simple policy implication of this work could be providing guidelines and reference material in local languages. Additional research is needed to more accurately measure performance to link network properties to patient outcomes as well as investigate the impact of turnover and absence on advice networks, ideally through a longitudinal network study. This study demonstrates the feasibility of using social network analysis methods in rural Ethiopia, which has implications for other African and low or middle-income countries. This study also shows the value of combining quantitative network methods with qualitative research to lend a greater understanding of network properties. Mixed SNA method studies should be used more widely in these contexts as they provide a different lens and understanding of professional advice networks in settings where resources for health are increasingly constrained and as such networks may be an efficient and effective way to change practice.

Declarations

Authors' contributions

KS Wrote the study protocol, managed ethical clearance, engaged the FMOH for input, conducted pre-testing, trained enumerators, entered and analysed data and wrote all drafts of the manuscript.

JS Guided conceptualisation of research questions, reviewed protocol, study tools, advised on data collection procedures and drafts of the manuscript.

KB Guided conceptualisation of research questions, reviewed protocol, study tools, advised social network analysis methods and analysis, and drafts of the manuscript.

DB Guided conceptualisation of research questions, reviewed protocol, along with KS engaged FMOH for input, reviewed study tools, advised on data collection processes and procedures, provided input into selection criteria and use of coverage data, and reviewed drafts of the manuscript.

NS Guided conceptualisation of research questions, reviewed protocol, study tools, advised on qualitative data methods and analysis, and reviewed drafts of the manuscript.

All authors reviewed the final version of the review.

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Table 1: PHCU characteristics

PHCU	Network size	Participant response rate	Number of Health Centres	Number of Health Posts	Total number of Facilities	Network Surveys Administered	Qualitative Interviews Conducted
PHCU A	19	95%	1	5	6	18	5
PHCU B	24	96%	1	3	4	23	0
PHCU C	19	100%	1	4	5	19	0
PHCU D	19	100%	1	4	5	19	5
PHCU E	15	100%	1	2	3	15	5
PHCU F	25	100%	1	5	6	25	0
PHCU G	17	100%	1	5	6	17	5
PHCU H	24	100%	1	7	8	24	0
Mean	20.25	0.99	1.00	4.38	5.38	20.00	2.50
Standard deviation	3.65	0.02	0.00	1.51	1.51	3.59	2.67
Total	**162**	**99%**	**8**	**35**	**43**	**160**	**20**

Table 2: Network survey respondent characteristics by cadre

Cadre	Number Male	Number Female	Total Number Respondents	Average Age	Average Years of Experience	Average Years at post
Health Officers	15	2	17	26.0	3.3	1.3
Midwives	4	17	21	23.5	1.9	1.3
Nurses	34	29	63	26.0	3.2	2.0
Health Extension Workers	1	58	59	25.1	4.7	3.8
Average/total	54	106	160	25.5	3.6	2.5

Table 3: Network-level SNA Metrics Grouped by Metric

Network-level SNA metrics	All networks (ALL)	All advice seeking networks (AS)	All advice-giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All new-born care advice seeking or giving networks (New-born)
Degree Centrality							
PHCU	ALL	AS	AG	ANC	MAT	PNC	Newborn
PHCU A	0.48	0.47	0.58	0.50	0.54	0.43	0.40
PHCU B	0.43	0.40	0.43	0.45	0.34	0.38	0.37
PHCU C	0.40	0.36	0.37	0.37	0.37	0.34	0.46
PHCU D	0.40	0.42	0.36	0.50	0.25	0.27	0.20
PHCU E	0.35	0.44	0.42	0.35	0.46	0.44	0.32
PHCU F	0.49	0.55	0.47	0.50	0.43	0.45	0.51
PHCU G	0.52	0.50	0.47	0.37	0.51	0.20	0.26
PHCU H	0.57	0.38	0.54	0.47	0.45	0.27	0.26
mean	0.45	0.44	0.45	0.44	0.42	0.35	0.35
standard deviation	0.08	0.06	0.08	0.06	0.09	0.09	0.11
Out Degree Centrality							
PHCU	ALL	AS	AG	ANC	MAT	PNC	Newborn
PHCU A	0.31	0.21	0.36	0.22	0.24	0.19	0.21
PHCU B	0.50	0.12	0.50	0.52	0.16	0.41	0.40
PHCU C	0.47	0.30	0.44	0.37	0.31	0.23	0.52
PHCU D	0.35	0.13	0.39	0.24	0.15	0.30	0.17
PHCU E	0.39	0.25	0.64	0.24	0.27	0.53	0.50
PHCU F	0.49	0.20	0.50	0.37	0.28	0.36	0.26

Network-level SNA metrics	All networks (ALL)	All advice seeking networks (AS)	All advice-giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All new-born care advice seeking or giving networks (New-born)
Out Degree Centrality (contd.)							
PHCU	ALL	AS	AG	ANC	MAT	PNC	Newborn
PHCU G	0.43	0.25	0.53	0.34	0.47	0.16	0.23
PHCU H	0.53	0.26	0.60	0.33	0.36	0.26	0.23
mean	0.44	0.22	0.49	0.33	0.28	0.30	0.32
standard deviation	0.08	0.06	0.10	0.10	0.10	0.12	0.14
In Degree Centrality							
PHCU	ALL	AS	AG	ANC	MAT	PNC	Newborn
PHCU A	0.54	0.56	0.18	0.57	0.53	0.43	0.27
PHCU B	0.41	0.48	0.18	0.34	0.39	0.18	0.13
PHCU C	0.35	0.36	0.26	0.31	0.43	0.23	0.23
PHCU D	0.47	0.36	0.45	0.41	0.27	0.18	0.23
PHCU E	0.46	0.63	0.18	0.39	0.49	0.22	0.19
PHCU F	0.58	0.63	0.20	0.45	0.45	0.40	0.43
PHCU G	0.43	0.45	0.13	0.27	0.27	0.09	0.23
PHCU H	0.35	0.45	0.19	0.29	0.36	0.07	0.10
mean	0.45	0.49	0.22	0.38	0.40	0.23	0.23
standard deviation	0.08	0.11	0.10	0.10	0.10	0.13	0.10

Network-level SNA metrics	All networks (ALL)	All advice seeking networks (AS)	All advice-giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All new-born care advice seeking or giving networks (New-born)
Density							
PHCU	ALL	AS	AG	ANC	MAT	PNC	Newborn
PHCU A	0.21	0.13	0.11	0.12	0.11	0.09	0.08
PHCU B	0.17	0.10	0.09	0.11	0.07	0.05	0.05
PHCU C	0.33	0.22	0.20	0.20	0.20	0.12	0.12
PHCU D	0.16	0.10	0.13	0.11	0.08	0.05	0.06
PHCU E	0.50	0.27	0.26	0.28	0.25	0.22	0.25
PHCU F	0.28	0.14	0.19	0.19	0.15	0.15	0.13
PHCU G	0.22	0.14	0.13	0.12	0.12	0.04	0.10
PHCU H	0.18	0.09	0.12	0.11	0.09	0.06	0.04
mean	0.26	0.15	0.15	0.16	0.13	0.10	0.10
standard deviation	0.11	0.06	0.06	0.06	0.06	0.06	0.07
Number of ties							
PHCU	ALL	AS	AG	ANC	MAT	PNC	New-born
PHCU A	71	45	36	42	37	32	26
PHCU B	94	56	49	61	36	25	28
PHCU C	113	74	68	69	69	41	41
PHCU D	56	35	45	37	26	17	20
PHCU E	104	56	55	58	53	47	52
PHCU F	166	85	111	113	88	92	77

Network-level SNA metrics	All networks (ALL)	All advice seeking networks (AS)	All advice-giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All new-born care advice seeking or giving networks (New-born)
Number of ties							
PHCU	ALL	AS	AG	ANC	MAT	PNC	New-born
PHCU G	60	39	35	33	33	11	26
PHCU H	101	52	68	63	52	33	21
mean	95.63	55.25	58.38	59.50	49.25	37.25	36.38
standard deviation	35.46	17.02	24.73	25.31	20.85	25.08	19.66
Distance							
PHCU	ALL	AS	AG	ANC	MAT	PNC	New-born
PHCU A	2.00	2.10	1.50	2.30	2.10	2.10	1.80
PHCU B	2.40	2.30	2.00	2.30	2.00	1.70	1.70
PHCU C	1.80	1.80	2.40	2.30	2.30	1.90	2.00
PHCU D	2.00	2.60	2.60	2.40	2.70	1.40	2.00
PHCU E	1.50	1.60	1.90	2.20	2.30	2.20	2.20
PHCU F	1.80	2.40	2.20	1.90	2.00	2.40	2.40
PHCU G	2.00	2.10	2.20	2.10	2.00	1.40	1.90
PHCU H	2.00	1.70	2.10	2.20	2.10	2.60	2.00
mean	1.94	2.08	2.11	2.21	2.19	1.96	2.00
standard deviation	0.26	0.35	0.33	0.16	0.24	0.44	0.22

Table 4: Actor-level metrics within each PHCU and network type: Cadre of actor with highest value

	Cadre and value of actor with the highest value SNA metric for each PHCU and network captured (Cadre abbreviations NS=nurse, MW=midwife, HEW=health extension worker, HO=health officer)						
PHCU	All networks (ALL)	All advice seeking networks (AS)	All advice-giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All new-born care advice seeking or giving networks (New-born)
Betweeness							
PHCU	ALL	AS	AG	ANC	MAT	PNC	New-born
PHCU A	MW (32.616)	HO (12.963)	MW (8.932)	MW (27.451)	MW (30.065)	MW (20.261)	HO (12.418)
PHCU B	MW (34.314)	MW (25.395)	MW (6.456)	NS (24.776)	MW (8.992)	MW (3.162)	MW (2.964)
PHCU C	NS (16.256)	NS (13.533)	NS (16.966)	MW (26.747)	MW (24.599)	NS (11.492)	NS (11.928)
PHCU D	NS (20.937)	MW (13.426)	NS (36.029)	MW (24.946)	MW (16.176)	NS(1.961)	NS (3.595)
PHCU E	HO (18.656)	NS (17.582)	NS (14.698)	NS (21.361)	NS (39.011)	MW (26.377)	NS (36.364)
PHCU F	NS (19.201)	MW (16.757)	MW (12.530)	NS (18.916)	NS (15.854)	NS (27.926)	NS (31.908)
PHCU G	MW (39.701)	HO (14.958)	MW (29.722)	MW (22.361)	MW (30.625)	HEW (2.5)	MW (13.125)
PHCU H	NS (27.803)	NS (8.696)	NS (16.614)	NS (23.142)	NS (20.487)	NS (11.133)	NS (6.719)
Out Degree Centrality							
PHCU	ALL	AS	AG	ANC	MAT	PNC	Newborn
PHCU A	MW (9)	HEW (6)	MW (8)	HO (6)	NS (6)	HO (5)	HO/HEW(5)

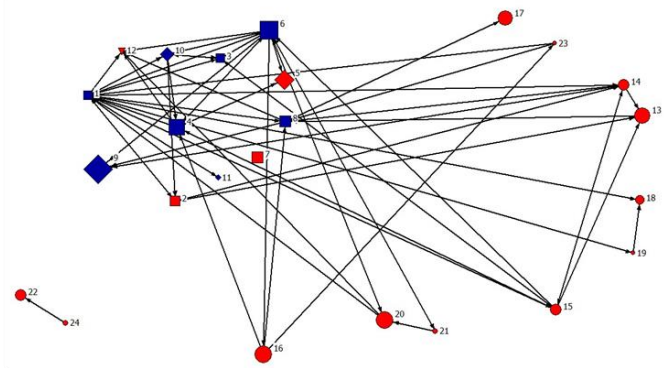
PHCU	Cadre and value of actor with the highest value SNA metric for each PHCU and network captured (Cadre abbreviations NS=nurse, MW=midwife, HEW=health extension worker, HO=health officer)						
	All networks (ALL)	All advice seeking networks (AS)	All advice-giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All new-born care advice seeking or giving networks (New-born)
Out Degree Centrality (contd.)							
PHCU	ALL	AS	AG	ANC	MAT	PNC	New-born
PHCU B	HO (13)	HO (13)	NS (6)	MW (10)	MW/NS (5)	MW (5)	NS (4)
PHCU C	NS (14)	NS (9)	NS (11)	NS (10)	NS (9)	NS (6)	NS (11)
PHCU D	NS (9)	NS/MW/MW (4)	NS (9)	MW (6)	NS (4)	NS (6)	NS (4)
PHCU E	HO (12)	NS (7)	HO (12)	NS (7)	HO (7)	NS (10)	NS (10)
PHCU F	NS (18)	MW/HEW (8)	NS/MW (16)	NS (13)	MW (10)	MW (12)	NS (9)
PHCU G	MW (10)	HO/HEW (6)	MW (10)	HEW (7)	MW (9)	HO/HEW (3)	HEW (5)
PHCU H	NS (16)	HEW (8)	NS (16)	NS (10)	NS (10)	NS (7)	NS (6)
In Degree Centrality							
PHCU	ALL	AS	AG	ANC	MAT	PNC	Newborn
PHCU A	MW (13)	MW (12)	MW (5)	MW (12)	MW (11)	MW (9)	HO/MW (6)
PHCU B	NS (15)	MW/NS (5)	NS (13)	NS (14)	HO (10)	NS (10)	NS (10)
PHCU C	MW (12)	MW (10)	MW (8)	MW (9)	MW (11)	MW (6)	MW (6)

PHCU	Cadre and value of actor with the highest value SNA metric for each PHCU and network captured (Cadre abbreviations NS=nurse, MW=midwife, HEW=health extension worker, HO=health officer)						
	All networks (ALL)	All advice seeking networks (AS)	All advice-giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All new-born care advice seeking or giving networks (New-born)
In Degree Centrality (contd.)							
PHCU	ALL	AS	AG	ANC	MAT	PNC	Newborn
PHCU D	MW (11)	MW (8)	MW (10)	MW (9)	MW(6)	MW (4)	MW (5)
PHCU E	HO (13)	HO (12)	HEW (6)	HO (9)	MW (10)	HO (6)	NS/HEW (6)
PHCU F	MW (20)	MW (18)	NS/MW (9)	MW (15)	MW (14)	MW (13)	NS (13)
PHCU G	MW (10)	MW (9)	HO/MW (4)	MW (6)	MW (6)	MW/HEW (2)	MW (5)
PHCU H	NS (12)	NS (12)	MW (7)	NS (9)	NS (10)	NS/HO/HEW (3)	NS (3)
Eigenvector Centrality							
PHCU	ALL	AS	AG	ANC	MAT	PNC	New-born
PHCU A	MW (40.4%)	HO (43.9%)	MW (54.3%)	MW (47.6%)	MW (50.6%)	MW (51.5%)	HO (53.2%)
PHCU B	MW (37.3%)	MW (40.9%)	NS (43.3%)	MW (40.4%)	HO (44.6%)	NS (55.6%)	NS (55.4%)
PHCU C	NS (33.9%)	NS (34.2%)	NS (36.9%)	NS (40.4%)	NS (35.1%)	NS (44.7%)	NS (46.8%)
PHCU D	MW (42.3%)	MW (48.7%)	MW (42.1%)	NS (38.8%)	NS (46.2%)	NS (54.8%)	MW (51.2%)
PHCU E	HO (34.8%)	HO (39%)	HO (39.1%)	HO (39.4%)	HO (41.4%)	NS (42.8%)	NS (38.8%)

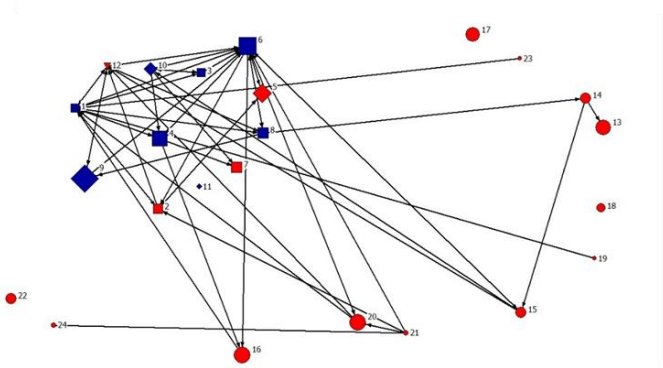
PHCU	Cadre and value of actor with the highest value SNA metric for each PHCU and network captured (Cadre abbreviations NS=nurse, MW=midwife, HEW=health extension worker, HO=health officer)						
	All networks (ALL)	All advice seeking networks (AS)	All advice-giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All new-born care advice seeking or giving networks (New-born)
Eigenvector Centrality (contd.)							
PHCU	ALL	AS	AG	ANC	MAT	PNC	New-born
PHCU F	NS (32.7%)	NS (38.7%)	MW (34.8%)	NS (37.2%)	NS (39.8%)	NS (36.6%)	NS (41.8%)
PHCU G	MW (46.8%)	MW (50%)	MW (49.8%)	MW/HEW (45.4%)	MW (58.8%)	HEW (56.9%)	MW (51.1%)
PHCU H	NS (42.0%)	NS (43.7%)	NS (44.7%)	NS (45.8%)	NS (49.8%)	NS (48.3%)	NS (59.9%)

Figure 1: PHCU "H" Dichotomized network sociograms

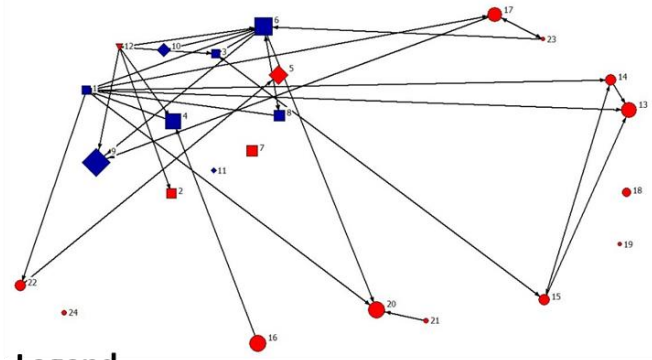
Antenatal Care Advice Exchange



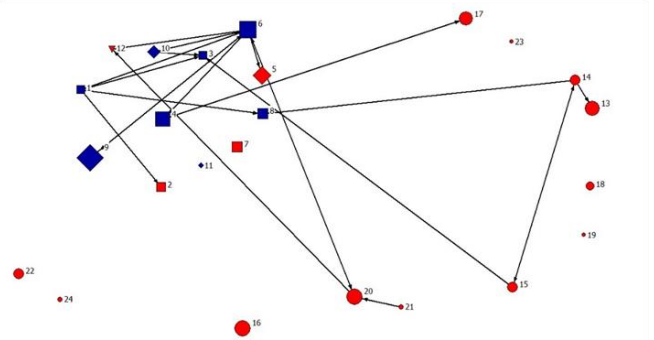
Maternity Care Advice Exchange



Postnatal Care Advice Exchange



Newborn Care Advice Exchange



Legend

Position=facility (grouped by facility)

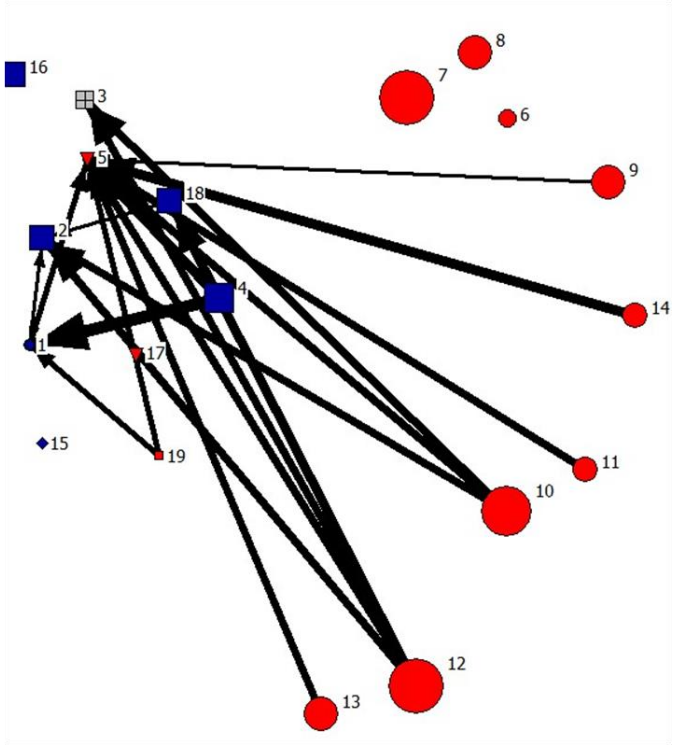
Colour=gender
Red= Female
Blue=Male

Shape Size=years of experience

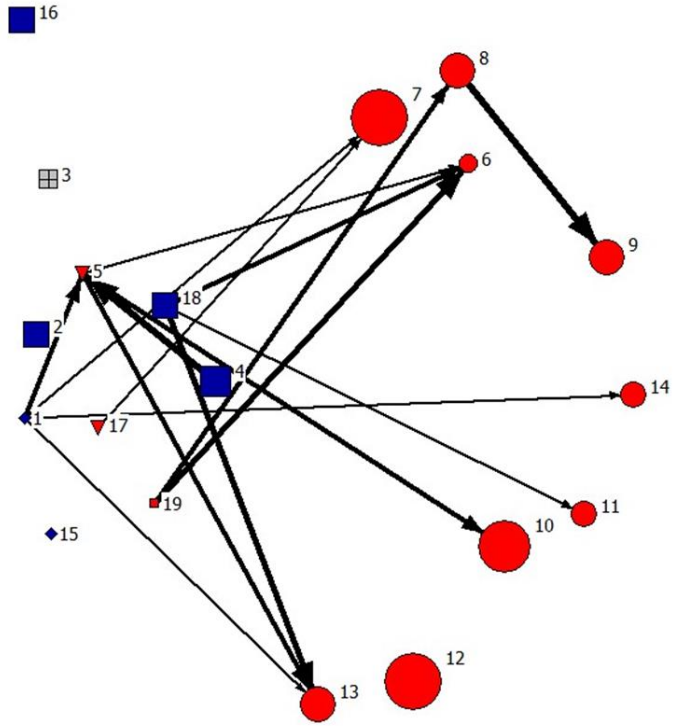
Shape=cadre
=HO =NS
=MW =HEW

Figure 2 : PHCU “A” Valued PNC Advice Seeking and Giving

PNC Advice-Seeking



PNC Advice-Giving



Legend
Position=facility
(grouped by facility)

Colour=gender
Red= Female
Blue=Male

Line width=advice frequency

Size=experience

Shape=cadre
=HO
=NS
=MW
=HEW

Figure 3: Valued Maternity Advice Seeking across PHCUs A, B, C and D

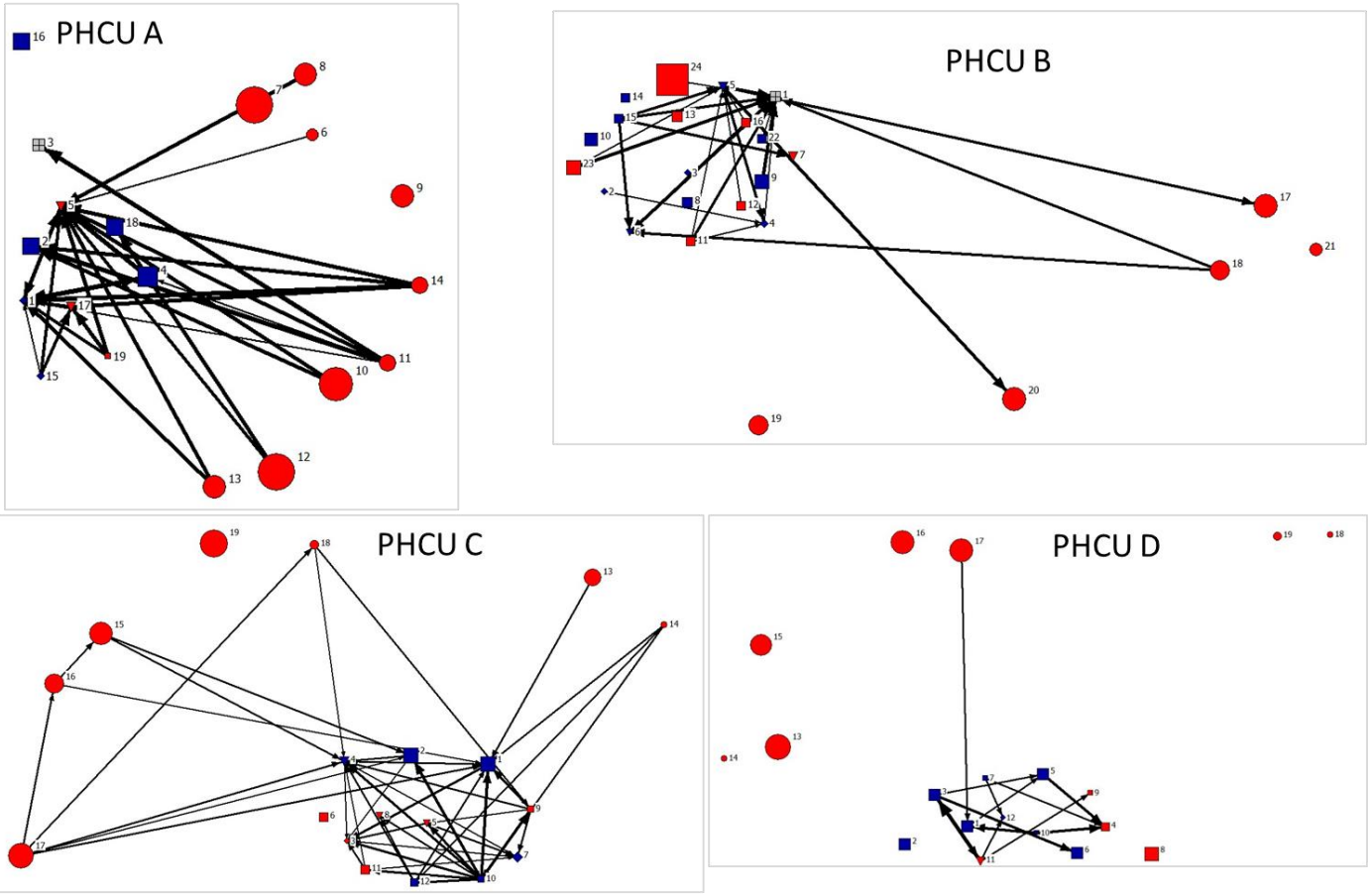
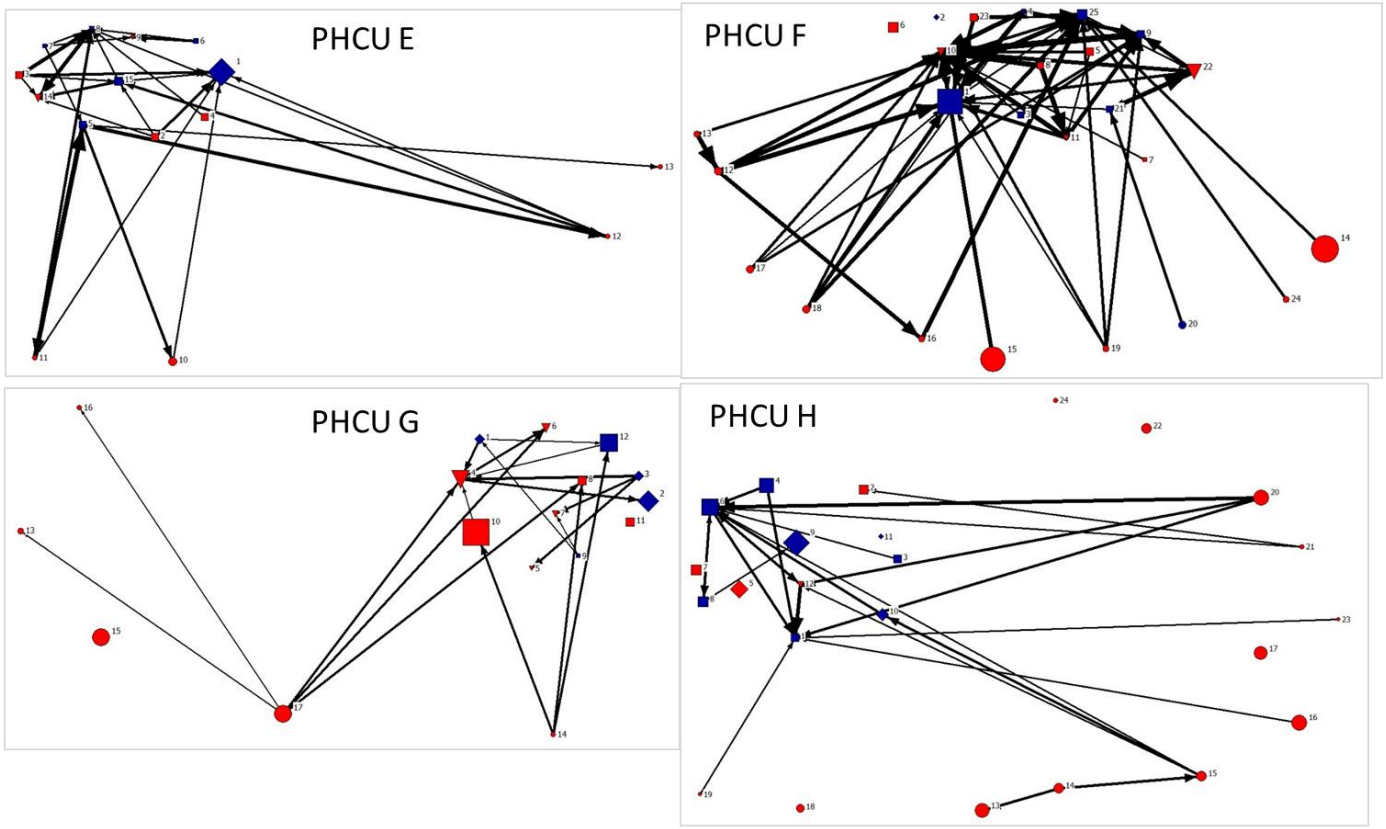


Figure 4: Valued Maternity Advice Seeking for PHCUs E, F, G and H



Legend
Position=facility
(grouped by facility)

Colour=gender
Red= Female
Blue=Male

Line width=advice frequency

Size=experience

Shape=cadre
=HO
=NS
=MW
=HEW

8 Results

8.1 Systematic Review

The findings are presented in Paper 1.

8.2 Ethiopia Network Study

The findings are presented in Paper 2.

9 Discussion

9.1 Limitations

Limitations are discussed in both papers. Below are additional limitations for the Network Study beyond what was described in Paper 2. Specifically, these limitations include possible data quality issues, data not analysed and potential additional analyses.

9.1.1 Potential Data quality issues

9.1.1.1 Language limitations

While there are studies of healthcare workers in Ethiopia that are only conducted in Amharic and this study was conducted in Amharic, Tigirinia and Oromifa, it remains possible that there were subtleties lost in translation for non-native speakers of these regional languages. This is particularly a possibility for HEWs in SNNP, where there is not a regional language, and they may not have had much education conducted in Amharic. Even in the regions where there are regional languages there are ethnic minorities for whom that will be their second language. While it would not have been possible to conduct the study on the scale proposed with enumerators fluent in every possible local language, as such we would not have changed the study design, we could have captured data to know if language was a meaningful barrier. Future studies should capture information on study participants' native speaking language and level of comfort in other languages to estimate the likely impact on the findings.

9.1.1.2 Misunderstanding of "informal professional advice exchange"

While a description was used to standardize the enumerator explanation of the communication of interest (see the footnote in section 4.2.7), it remains possible that respondents had different understandings. For example, it may have been unclear if informal conversations during formal trainings qualified as the informal professional advice exchange of interest. However, as formal trainings are relatively rare events, it is not anticipated to have been a major data quality issue.

9.1.2 Data not analysed

9.1.2.1 Performance

The performance data were unusable. The data collection tools used were the same ones used for the CBNC baseline and midline evaluation. The midline data collection had been completed two months prior to the network study using the same enumerators. Despite selecting tools previously used in these facilities by the same enumerators, the data were internally inconsistent, but more importantly, inconsistent to previous data from these health facilities using the same tool. In consultation my supervisor and committee members, I decided to not use these data for the purposes of linking performance to network properties. It was tempting to go ahead and do the analyses, but knowing the data quality issues I was concerned that the findings could be misleading given their foundation.

9.1.2.2 GPS Data

The GPS coordinate data captured from health post and health centre have not been used to date. Initially this was out of concern that such data could reveal the specific locations and compromise confidentiality of study participants. Upon further reflection there may be a way to integrate these data without showing facilities on a map. Rather using distance between health posts and their health centre as an attribute or possibly structure a regression using this as a variable to predict network properties. In future analyses I may do that.

9.1.3 Additional Analyses

There are many additional ways that I can analyse the available dataset. Some network analysts spend their careers analysing datasets smaller than what is discussed here. For the purposes of completing my DrPH, I have limited the papers to two and included only one using the Ethiopia SNA study data. While I do not necessarily see myself as a network analyst moving forward, I do see the potential for several more papers to further explore the data captured through this study. Each of these service delivery areas (antenatal, childbirth, postnatal and newborn care) could have a separate paper looking at their advice seeking and giving networks. Valued data were only considered in the visualisations, there is much more that can be done to understand how frequency of advice exchange factors into the cadres engaged in advice exchange. The visualisations could be further explored using different approaches for grouping actors either by other attributes, actor-level network metrics or using other algorithms for arranging actors within a sociogram. The current visualisations grouped the actors by a single attribute, the facility of employment (Importantly, this grouping was not based on the actual physical, geographic distance between these facilities, but rather grouped by the attribute and then manually adjusted for greater clarity of the relationships

between actors). Subnetwork structures could be explored further. The generation of a roster of PHCU healthcare workers during the qualitative inquiry provides an opportunity to look at turnover by cadre. This analysis would be limited to those PHCUs for which we have rosters captured during the qualitative inquiry.

9.2 Research implications

The research implications discussed here are intended to complement and expand upon those discussed in each of the two papers presented.

9.2.1 Systematic review

The systematic review highlighted the lack of existing studies of health provider professional advice networks with any link to performance, in primary health care settings and particularly in LMIC and African contexts. It provided a summary of SNA methods and metrics used to answer research questions exploring health provider professional advice networks and performance. For commonly used metrics (centrality and density) the review summarised the relationship associated with performance as indicated by the existing studies. It identified existing systematic reviews of SNA in health and described their focus and findings. This piece of work is a signpost, it indicates where research is now, which is not where it needs to be to understand the relationship between network properties and performance for health provider professional advice networks. Six studies are insufficient to draw conclusions on the relationship between network properties and professional advice networks. It is not possible to design network interventions with confidence given the current evidence base. Further studies are needed describing the association between professional advice network properties and patient outcomes before conclusions can be drawn around what characterises “healthy” professional advice networks and design interventions to shape these networks accordingly.

9.2.2 Ethiopia Network Study

Professional advice networks have the potential to improve implementation of health programs. This is particularly relevant in the context of resource constrained settings with large numbers of health care workers in need of updating on new treatment or practice guidelines. This study demonstrated the feasibility of conducting a network study of primary health care providers’ advice networks in a LMIC, African context. It also showed that such studies can yield findings different from those found in other settings. While not surprising, this study reconfirmed that it is not valid to conduct studies in western contexts and assume their learnings apply to LMIC, African or Ethiopian contexts. If, as I argue, network based solutions should be explored in LMIC contexts to

enhance and harness existing health professional advice networks, then additional research is needed in these contexts.

Not all data collection methods for SNA are possible in part due to the lack of electronic data linked to health providers that can be found in some Western, tertiary settings. This is supported by the publication bias found in the systematic review. Rosters are not possible to accurately generate until you are in the field, thus limiting use of electronic data collection using PDAs for certain types of network studies of professional advice networks. This is not a context in which publication networks or conferences or professional associations will be fora in the near future for primary health care provider advice networks to flourish or yield easy-to-conduct SNA studies. While this may be changing as electronic data expands in some LMIC and internet and cellular data availability expands options for egonet survey data, it is likely to continue to be a limitation for SNA study designs relying on certain types of data captured from individuals. Professional network studies may need to explore other platforms as connectivity evolves in LMIC and African contexts. Platforms like WhatsApp may ultimately be a way to develop and learn about professional advice networks. Telecommunications platforms within the Ethiopian context may be more limited.

Methodologically, this study showed the value of combining quantitative network methods with qualitative inquiry to ground the network findings in a contextual understanding.

9.3 Areas for future research

9.3.1 Emerging from the Ethiopia Network Study

There are several areas for future research that flow directly from the Ethiopia Network Study and would be necessary to inform potential policies that could be developed to harness professional advice networks. These include testing cadre-based training models, strengthening the supportive supervision delivery model and exploring the advantages and disadvantages of having transient health centre staff with respect to PHCU professional advice networks.

9.3.1.1 Network informed, cadre-based Training Model

In addition to a “knowledge sharer” PHCU role described in the policy implications section above, other models for training a subset of healthcare workers drawing on professional advice networks could be considered. The Ethiopia Network Study suggests that midwives are more central actors. The next time a new programme needs to be introduced, one option could be experimenting with training different individuals based on their cadre and the area of focus for the programme and see if the same or better learning objectives are achieved for the whole PHCU.

9.3.1.2 Exploring Supportive Supervision Models as Advice Exchange Platforms

One of the clear findings emerging from the Ethiopia Network Study was that the supportive supervision visits were not the forums for advice exchange that they could be. The potential of supportive supervision visits as advice exchange fora for PHCU staff still have yet to be realised in Ethiopia and elsewhere. Previous work found that supervision of HEWs was not an opportunity for feedback [1]. While supportive supervision visits were mentioned, they were not the focus of respondents in describing their advice networks. While this could be an artefact of not directly asking the role of supportive supervision in advice exchange, the qualitative inquiry asked about the context surrounding advice exchange and for one PHCU found the advice exchange did not correspond to the formal supervisory structures. So while it remains possible that this finding is a product of data collection, I find this unlikely. The apparent gap in actualization of the supportive supervision role and visits could in part be due to the inconsistency of such visits, as has been previously reported in Ethiopia and other LMIC [2]. Further research is needed. Specifically, I recommend three studies:

1. a review of the existing literature on supportive supervision—what works in terms of structure and frequency. This would build on existing reviews and studies of models for supportive supervision [3-5].
2. a qualitative study exploring the dynamics of existing supportive supervision visits could reveal how to enhance these visits so they are for a for advice exchange. Such a study would look at the composition of the supportive supervision team, their training, their mandate, the tools used, the assessment of supportive supervision visits themselves, follow up procedures, and barriers to meeting the frequency of intended visits.
3. an intervention study that could test models for adjusting supportive supervision such that they achieve this vision for being a forum for professional advice exchange.

In considering this research agenda, it would be important to engage the FMOH closely in the design of these studies such that only models and interventions that could be taken to scale are considered.

9.3.1.3 Health Centre Staff Mobility and Advice Networks: good or bad?

The delay in data collection between the quantitative survey and the qualitative interviews revealed that PHCU staff are highly mobile, with the exception of HEWs. Health centre staff are regularly transferred and often are away for periods of time for trainings. While our data do not allow for much beyond speculation on the impact of this mobility on professional advice networks, there are possible advantages and disadvantages. The network study found that rotating staff expands the

base for seeking advice as some PHCU staff reported reaching out to transferred staff with whom they had a relationship and respected their knowledge and advice. As connectivity improves this may be preferred. However, the movement of PHCU staff may limit relationship building and trust that can facilitate advice exchange. Encouragingly, our results suggest that provider ego in admitting knowledge limitations plays less of a barrier in seeking advice than in other contexts. As such relationship building and trust may be less relevant. More research is needed to further explore the effect of PHCU staff mobility on advice networks. Specifically, it would be helpful to have a longitudinal network study, capturing performance, that monitors staff mobility. In a perfect world a controlled intervention study would allow for limiting mobility of PHCU staff in a subset of PHCUs during the study to test the effect of mobility on advice networks. It would be important to document health centre staff morale and what drives the transience, staff requests for transfers, further training opportunities or FMOH needs.

9.3.2 Other areas for further research

Separately from research areas and questions directly emerging from the Ethiopia Network Study findings, there are a range of research questions, that if answered would help guide policy makers to more effectively harness professional advice networks. Below is an illustrative list of some questions for future research studies.

- What network characteristics signal a functional professional advice network, whereby advice needs are met and providers can quickly and with fidelity implement new programmes or change their behaviours in LMIC, primary health care ,African contexts?
- Is there an association between professional advice network properties and patient outcomes?
- What types of network interventions are most effective at enhancing or changing professional advice networks, in LMIC, primary care African contexts?
- What types of network interventions are feasible to implement in LMIC, primary care African contexts?
- What kinds of network interventions are scalable in LMIC, primary care African contexts?
- How can technology, such as mhealth, ehealth or telemedicine be integrated to enhance existing professional advice networks?
- How effective are network interventions at changing health care provider professional behaviours relative to traditional training methods?

- What cost is associated with network interventions and how does that compare to traditional methods of changing health care provider professional behaviours and practices?

The types of interventions that could be studied are numerous. In the above sections some possible interventions are discussed as specific next steps emerging from this network study. Below is a description of a possible intervention, addressing one of the research questions above and the types of studies and data that should be collected to evaluate the intervention and inform implementation. This is merely illustrative as this is a nascent area for research, many studies could be considered.

9.3.2.1 Example: Telemedicine and Professional Advice Networks

Technological interventions present a unique opportunity in some LMIC and African contexts. Recent systematic reviews found opportunity for mHealth applications in Africa, particularly for supporting rural health care providers in need of specialist advice and that professional networks influence adoption by health providers in Africa [6-7]. I have begun advising Health-E-Net [8], a model for connecting rural health care providers in Kenya with specialist consultations. The tablet or smartphone interface allows providers to document the case, specify their questions and connect with a volunteer specialist for their advice. Health-E-Net are developing their algorithm to automatically link providers to specialists, which will be important when taking this to scale. They want to explore how social network analysis may inform their algorithm. Their hypothesis is that by better understanding existing advice networks and the dynamics around why certain providers are sought for advice, they may be able to more effectively meet advice needs and increase demand for and use of their service. This example has several network-based intervention opportunities and associated research questions.

The first intervention is the provision of the tablet or smart phone, or downloading the software onto a provider's existing device to facilitate external consults to supplement their existing professional advice networks. To evaluate this intervention impact on professional advice seeking behaviour, prior to introducing this intervention network data would be captured from providers to understand baseline advice network composition, use in terms of content areas, frequency of advice seeking, rates of patient referrals and reasons for referrals (as ideally such an intervention would allow, when appropriate, for patients to be treated locally rather than referred) and if their advice needs are being met. Ideally following the intervention these data would be collected again and analysed alongside individual provider use of the system.

Separately, to inform governments considering integrating such an intervention more broadly into a health system, this tool could be introduced with a subset of health care providers, those who are central to existing professional advice networks. This would allow more targeted allocation of resources, but hopefully achieve the same results in utilisation of the system and meeting health care worker advice needs. This may also be a more cost-efficient approach. Prior to considering such an intervention, a research study would need to be conducted comparing this type of implementation to other models of implementing this tool. First there would need to be a baseline conducted in the control area as well as the intervention area to identify those central actors in existing advice networks, to identify existing advice network use both in terms of content and frequency and if advice networks are meeting provider needs. Then after the intervention a follow up network survey should capture these same metrics to see if the intervention with a targeted number of central individuals in the advice networks is just as effective as linking all providers to such a platform and how that compares to the existing advice networks.

The expansion of the evidence base would assist policy makers in considering how to use telemedicine to enhance professional advice networks to improve service delivery. This is just one expanded example of the direction professional advice network studies in LMIC, African context could take.

9.4 Policy implications

The policy implications discussed here are intended to complement and expand upon those discussed in the second paper. There is an inherent challenge in separating out the research implications from the policy implications from the areas for future research as they are all intertwined. At this stage, most policy implication of this study still require further operational research to guide policy decisions and implementation.

9.4.1 "the Knowledge Sharer"

One of the most compelling findings of the Network Study are that existing supervisory networks do not feature prominently in professional advise networks and that perceived knowledge and expertise matter more than experience when it comes to who is sought for informal advice. This emphasis on perceived expertise could be harnessed by identifying an individual or two within each PHCU to be the focal point for knowledge sharing with a clear mandate to share new information. Ethiopia was able to roll out a new cadre at an impressive scale. If piloted and shown to be effective, this type of policy intervention could be easily scaled and allow for more targeted training. Rather than aiming to train all HEW and orient all other PHCU staff on CBNC, instead this approach could

train a fraction of the health work force and give them a mandate to focus on this knowledge translation and mentoring. While past programme introductions have used a model of cascading trainings, the individuals selected for training did not have this role more broadly outside of the one-off training. Perhaps if this "knowledge sharer" is a formal role within the PHCU this aspect of their work will have greater focus. A key issue would be ensuring that any HCW in such a role is fully orientated to the breadth of HEW roles and responsibilities as previous research indicated this disconnect was a frustration expressed by HEW supervised by health centre staff.[1]

9.4.2 Guidelines in Local Languages

Reasons given for advice exchange included more junior staff lacking confidence and a language barrier. The Ethiopian FMOH may consider providing guidelines and reference material in local languages beyond Amharic to make them more useful for primary health care unit staff. This would be relatively easy to implement – "a quick win" – given there are not many local languages that would be relevant for most of the agrarian regions, where the bulk of the population in Ethiopia live. Oromifya, Tigrinia the additional languages this study was conducted in could serve as a starting point.

9.4.3 Additional Mobile Phone credit allowances

Connectivity was mentioned as a barrier, but mostly in the recent-past, indicating improving connectivity. Given that many advice exchanges occur over the phone, a policy implication could be exploring to see if providing health care workers with additional credit on their phones affects advice network activity. Ideally such a policy consideration would be piloted, carefully documenting advice network metrics before and after such an intervention and capture performance to see if the assumed greater advice network activity would result in improved patient outcomes.

Aside from providing guidelines and reference materials to health care workers in local languages, it would be appropriate to pilot, monitor and evaluate any of these proposed policy changes prior to implementation.

9.5 Conclusion

This is a call for further studies of professional advice networks in primary care, LMIC and African contexts. Professional advice networks are untapped avenues for improving implementation and changing provider behaviour. Ideally such studies would incorporate a scalable, network-based intervention. Such intervention studies should include formative research capturing performance data to build the evidence base and justification for network interventions in these contexts. Ideally controlled trials would allow for comparing outcomes of the intervention arm to that of the control

arm. However, complexities of care delivery and the fluidity of networks may limit study design options. Longitudinal studies would be helpful to document the effects of interventions intended to support professional advice exchange.

10 Overall Conclusion

Professional advice networks are an underutilised avenue to improve health programme implementation and influence health provider behaviour. As resources are increasingly constrained all opportunities to influence providers or improve programme implementation more efficiently must be explored. Previous HCW in-service training models have limitations as the right individuals are not always selected and in the future there may not be resources for such models of formal in-service training. Guidelines and protocols will continue to evolve and the need for changing behaviours of health care providers will not resolve only by changing pre-service curricula. This body of work shows that SNA methods can be used in rural primary health care contexts and provides a foundation for future studies to build upon to explore how these networks can be harnessed to address the challenge of continuous learning. The final frontier remains exploring network-based interventions.

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12 Annexes

12.1 Paper 1 Additional Files

Additional File 1: Search strategy concepts and associated terms

Social network analysis	**Diffusion of innovations**	**Knowledge translation & transfer**
Social network	Diffusion of innovation*	Integrated knowledge translation
analysis method*	Diffusion or diffusivity	Knowledge mobili#ation
analysis technique*	characteristic*	Knowledge to action
approach	evidence	Transmission of knowledge
data	information	Knowledge
diagrams	innovation	utili#*
examin*	innovation adaptation	uptake
explor*	innovation adoption	transfer*
framework	knowledge	disseminati*
indicator	map	translation
information	measurement	broker
inquiry	model	exchange
interaction*	pathway*	generation
intervention	pattern*	integration
investigation*	process*	diffuse*
map*	propert*	Evidence
measure*	simulation*	exchange
method*	strateg*	transfer
metric	stud*	uptake
model	system*	utili#*
pattern	technique*	diffuse*
perspective	theor*	transl*
questionnaires	theory model*	implement*
software	Innovation	Data
structure*	adopt*	exchange
surveys	adaptation*	transfer
techniques	development process	transl*
theory	sharing	Research
tools	exchange	utili#*
Interprofessional relations	Program adopt*	transl*
Network intervention	Innovation adoption and diffusion	implement*
Sociometr* techniques	Innovation* in service delivery and organi#ation	Information
Sociogram*		dissemination
Sociomap*		exchange
Interprofessional relations		transfer
Network intervention		transl*
Network stud*		Organizational innovation
change agent*		Continuing education
opinion leader*		Policy
champion*		Quality improvement
knowledge broker		Total quality management
opinion leader*		Knowledge management
UCINET		Evidence-based practice
full list of SNA software in example search strategy		Evidence-based medicine
		Guideline implementation
		Policy research

Social network analysis	Diffusion of innovations	Knowledge translation & transfer
		Policies
		Participatory action research
		Effective dissemination
		Complex intervention
		Communit* of practice
		Applied dissemination
		Implementation science
		Action research
		Adoption
		Linkage and exchange
		Best practi?e
		Change
		Dissemination
		Evaluation
		Implementation
		Implementation research
		Information
		Innovation
		Institutionali#ation
		Service innovation
		Translational research
		Utili#ation

Paper 1 Additional File 2: SNA software search strategy for each database

Database	Included	Excluded
Medline	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP, NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions, Network Workbench, Pajek, Sentinel Visualizer, SocNetV, visone, CID-ABM, C-IKNOW, Commetrix, MetaSight, Referral Web, SONIVIS, CiteSpace, E-Net, Ego Net, VennMaker, Financial Network Analyzer, PGRAPH, PermNet, CFinder, KeyPlayer, KliqFinder, Network Genie, ONA surveys, NodeXL, MatMan, yFiles, LibSNA, NetworkX, UrlNet, igraph, latentnet, RSiena, statnet or tnet	SNAP, InFlow, STRUCTURE, ORA, Jung, UNISoN, Puck, Blanche, Pnet and ORS
EMBASE	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP, NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions, Network Workbench, Pajek, Sentinel Visualizer, SocNetV, visone, CID-ABM, C-IKNOW, Commetrix, MetaSight, Referral Web, SONIVIS, CiteSpace, E-Net, Ego Net, VennMaker, Financial Network Analyzer, PGRAPH, PermNet, CFinder, KeyPlayer, KliqFinder, Network Genie, ONA surveys, NodeXL, MatMan, yFiles, LibSNA, NetworkX, UrlNet, igraph, latentnet, RSiena, statnet or tnet	SNAP, InFlow, STRUCTURE, ORA, Jung, UNISoN, Puck, Blanche, Pnet and ORS
PsychInfo	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP, NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions, Network Workbench, Pajek, Sentinel Visualizer, SocNetV, visone, CID-ABM, C-IKNOW, Commetrix, MetaSight, Referral Web, SONIVIS, CiteSpace, E-Net, Ego Net, VennMaker, Financial Network Analyzer, PGRAPH, PermNet, PNet, CFinder, KeyPlayer, KliqFinder, Network Genie, ONA surveys, NodeXL, MatMan, yFiles, LibSNA, NetworkX, UrlNet, igraph, latentnet , RSiena, statnet or tnet	SNAP, InFlow, STRUCTURE, ORA, Jung, UNISoN, Puck, Blanche and ORS
CINAHL	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP, NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions, Network Workbench, ORA, Pajek, Sentinel Visualizer, SocNetV, visone, CID-ABM, C-IKNOW, Commetrix, MetaSight, Referral Web, SONIVIS, UNISoN, CiteSpace, E-Net, Ego Net, VennMaker, Financial Network Analyzer, PGRAPH, Puck, Blanche, PermNet, PNet, CFinder, KeyPlayer, KliqFinder, Network Genie, ONA surveys, NodeXL, MatMan, JUNG, yFiles, LibSNA, NetworkX, UrlNet,igraph, latentnet, RSiena, statnet or tnet	SNAP, InFlow, STRUCTURE and ORS
Global Health	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP, NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions, Network Workbench, Pajek, Sentinel Visualizer, SocNetV, visone, CID-ABM, C-IKNOW, Commetrix, MetaSight, Referral Web, SONIVIS, CiteSpace, E-Net, Ego Net, VennMaker, Financial Network Analyzer, PGRAPH, PermNet, CFinder, KeyPlayer, KliqFinder, Network Genie, ONA surveys, NodeXL, MatMan, yFiles, LibSNA, NetworkX, UrlNet, igraph, latentnet, RSiena, statnet or tnet	SNAP, InFlow, STRUCTURE, ORA, Jung, UNISoN, Puck, Blanche, Pnet and ORS

Database	Included	Excluded
Social Policy and Practice	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP, NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions, Network Workbench, Pajek, Sentinel Visualizer, SocNetV, visone, CID-ABM, C-IKNOW, Commetrix, MetaSight, Referral Web, SONIVIS, UNISon, CiteSpace, E-Net, Ego Net, VennMaker, Financial Network Analyzer, PGRAPH, PermNet, Puck , Blanche, CFinder, KeyPlayer, KliqFinder, Network Genie, ORS, ONA surveys, NodeXL, MatMan, yFiles, LibSNA, NetworkX, UrlNet, igraph, latentnet, RSiena, statnet or tnet	SNAP, InFlow, STRUCTUREand ORA
HMIC	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP, NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions, Network Workbench, Pajek, Sentinel Visualizer, SocNetV, visone, CID-ABM, C-IKNOW, Commetrix, MetaSight, Referral Web, SONIVIS, UNISon, CiteSpace, E-Net, Ego Net, VennMaker, Financial Network Analyzer, PGRAPH, PermNet, Puck , Blanche, CFinder, KeyPlayer, KliqFinder, Network Genie, ORS, ONA surveys, NodeXL, MatMan, yFiles, LibSNA, NetworkX, UrlNet, igraph, latentnet, RSiena, statnet or tnet	SNAP, InFlow, STRUCTURE and ORA
Web of Science	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP, NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions, Network Workbench, Pajek, Sentinel Visualizer, SocNetV, visone, CID-ABM, C-IKNOW, Commetrix, MetaSight, Referral Web, SONIVIS, CiteSpace, E-Net, Ego Net, VennMaker, Financial Network, Analyzer, PGRAPH, PermNet, CFinder, KeyPlayer, KliqFinder, Network Genie, ONA surveys, NodeXL, MatMan, yFiles, LibSNA, NetworkX, UrlNet, igraph, latentnet, RSiena, statnet or tnet	SNAP, InFlow, STRUCTURE, ORA, Puck and ORS
The Cochrane Library	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP, STUCTURE, NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions, Network Workbench, ORA, Pajek, Sentinel Visualizer, SocNetV, visone, CID-ABM, C-IKNOW, Commetrix, MetaSight, Referral Web, SONIVIS, UNISoN, CiteSpace, E-Net, Ego Net,VennMaker, Financial Network Analyzer, PGRAPH, Puck, Blanche, PermNet, PNet, CFinder, KeyPlayer, KliqFinder, Network Genie, ONA surveys, NodeXL, MatMan, JUNG, yFiles, LibSNA, NetworkX, UrlNet, igraph, latentnet, RSiena, statnet or tnet	SNAP, InFlow and ORS
Popline	UCINET, NetDraw, KrackPlot, NetMiner, StOCNET, GRADAP,NEGOPY, FATCAT, MultiNet, Agna, Blue Spider, DyNet, MDLogix Solutions,Network Workbench, ORA, Pajek, Sentinel Visualizer, SocNetV, visone, CIDABM, CIKNOW, Commetrix, MetaSight, SONIVIS, CiteSpace, ENet, Ego Net, VennMaker, Financial Network Analyzer, PGRAPH, Puck, Blanche, PermNet, CFinder, KeyPlayer, KliqFinder, Network Genie,ONA Surveys, NodeXL, MatMan, LibSNA, igraph, latentnet, RSiena, statnet or tnet	SNAP, InFlow, STRUCTURE and ORS

Paper 1 Additional File 3: **K* Search Strategy Development**

Terms appearing in two or more sources were included in the search strategy. Those highlighted in blue technically only appeared in one source, however upon further investigation another iteration of the term (with an adjacency factor) appears in another source, therefore they are included. Those highlighted in orange were included in the Diffusion of Innovation search strategy. Depending on the database additional terms were included to ensure more litmus test articles were included in the search. In some databases some of the following terms yielded thousands and in some cases, millions of off topic articles, in those cases the terms were removed from the strategy. For example, "adoption" in most databases referred to adoption of children, rather than adoption of innovations. Therefore, the term "adoption" was removed in those situations. Other terms that were removed in certain cases included "change", "use", "utilization", "information" and "policy". All changes were documented in a search log.

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
Action Research	X					X	2
Adoption	X	X	X				3
Applied Dissemination	X					X	2
Best practi?e	X	X	X				3
Change	X	X	X				3
Communit$ of practice	X		X				2
Complex intervention		X	X				2
Continuing Education	X	X	X				3
Diffusion	X		X				2
Diffusion of Innovation	X	X	X		X	X	5
Dissemination	X	X	X				3
Effective dissemination	X					X	2
Evaluation	X	X	X				3
evidence adj2 diffusi$					X	X	2
evidence adj2 implement$					X	X	2
evidence adj2 tranlsat$					X	X	2
evidence adj2 utili#$					X	X	2
Evidence-based medicine	X					X	2
Evidence-based practice	X					X	2

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
Implementation	X	X	X				3
Implementation adj3 research		X	X				2
Implementation research	X	X				X	3
Implementation science	X					X	2
information	X	X	X				3
innovation	X	X	X				3
Institutionali#ation	X	X	X				3
Integrated knowledge translation	X					X	2
knowledge adj2 diffusion					X	X	2
knowledge adj2 dissemination					X	X	2
knowledge adj2 transfer					X	X	2
knowledge adj2 uptak$					X	X	2
knowledge adj2 utili#$					X	X	2
Knowledge broker$				X		X	2
Knowledge exchange	X			X			2
Knowledge generation				X		X	2
Knowledge integration	X					X	2
Knowledge management	X		X				2
Knowledge mobli#ation	X			X		X	3
Knowledge to action	X					X	2
Knowledge transfer	X			X			2
Knowledge translation	X			X			2
Knowledge uptake	X			X			2
Linkage and exchange	X	X	X			X	4
Organizational innovation	X	X	X		X		4
Participatory Action Research	X		X				2
policies		X	X				2

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
Policy	X	X	X				3
Policy research	X					X	2
Quality Improvement	X	X	X				3
research adj2 implement$					X	X	2
research adj2 transl$					X	X	2
research adj2 utilizat$					X	X	2
Service innovation	X	X	X				3
Total Quality Managment	X		X				2
Translational research	X	X	X				3
Use	X		X				2
Utili#ation	X	X	X				3
Applied Health Research	X						1
Audit	X						1
Behavi?or$ adj2 chang$						X	1
Behavio?r utili#ation	X						1
Business case						X	1
Capacity building	X						1
Change implementation	X						1
Clinical and translational science	X						1
Cognitive Application	X						1
Collaborative Development	X						1
Communication	X						1
Communicative utilization	X						1
Communit$ based research						X	1
Comparative effectiveness research	X						1
Complexity Science	X						1
Conceptual utili#ation	X						1
Confirmatory utili#ation	X						1

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
Continuing Medical Education	X						1
Continuing Nursing Education	X						1
Continuing Professional Development	X						1
Cooperation	X						1
Co-optation	X						1
Crossing the Quality Chasm	X						1
Data adj2 diffusing						X	1
Data adj2 diffusion						X	1
Data adj2 dissemination						X	1
Data adj2 exchange						X	1
Data adj2 linking						X	1
Data adj2 network?						X	1
Data adj2 partnership						X	1
Data adj2 shar$						X	1
Data adj2 transfer						X	1
Data adj2 translat$						X	1
Data broker				X			1
Data exchange				X			1
Data generation				X			1
Data mobili#ation				X			1
Data transfer				X			1
Data translation				X			1
Data uptake				X			1
Decision making					X		1
Disconfirmatory utili#ation	X						1
Educational$ influential$	X						1
Effectiveness research	X						1
end of grant knowledge translation	X						1
Evaluation research	X						1

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
evidence adj2 aware$						X	1
evidence adj2 exchange						X	1
evidence adj2 impact						X	1
evidence adj2 link$						X	1
evidence adj2 network?						X	1
evidence adj2 partnership						X	1
evidence adj2 shar$						X	1
evidence adj2 transfer						X	1
evidence adj2 uptak$						X	1
Evidence based healthcare	X						1
Evidence based nursing	X						1
Evidence broker				X			1
Evidence exchange				X			1
Evidence generation				X			1
Evidence informed decision making						X	1
Evidence informed practi#e	X						1
Evidence mobili#ation				X			1
Evidence transfer				X			1
Evidence translation				X			1
Evidence uptake				X			1
Evidence-based decision making						X	1
External validation	X						1
Feedback	X						1
Gap Analysis	X						1
guideline adherence						X	1
Guideline Implementation	X						1
Guideline* adj3 diffusion					X		1

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
Guideline* adj3 implementation					X		1
Guideline* adj3 translation					X		1
Guideline* adj3 utili#ation					X		1
Healthcare innovation	X						1
impact	X						1
Implementation adj2 program$					X		1
Implementation adj2 strateg$					X		1
improv$ adj3 knowledge						X	1
improv$ adj3 learning						X	1
improv$ adj3 practi#e?						X	1
Increase adj2 implementation					X		1
Industry liaison						X	1
information adj2 diffusing						X	1
information adj2 diffusion						X	1
information adj2 dissemination						X	1
information adj2 exchange						X	1
information adj2 link$						X	1
information adj2 network?						X	1
information adj2 partnership						X	1
information adj2 shar$						X	1
information adj2 spread$						X	1
information adj2 transfer						X	1
information adj2 translat$						X	1
Information broker				X			1
Information dissemination						X	1
Information exchange				X			1
Information generation				X			1

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
Information mobili#ation				X			1
information science	X						1
Information transfer				X			1
Information translation				X			1
Information uptake				X			1
innovation adaptation	X						1
innovation adj2 adopt$						X	1
innovation adj2 implement$						X	1
Innovation adoption	X						1
innovation adoption and diffusion	X						1
innovation development process	X						1
innovations in health service delivery and organization	X						1
Integrated knowledge transfer						X	1
internal validation	X						1
Know-do gap	X						1
knowledge adj2 diffusing						X	1
knowledge adj2 exchange						X	1
knowledge adj2 implementation					X		1
knowledge adj2 linking						X	1
knowledge adj2 network?						X	1
knowledge adj2 partnership						X	1
knowledge adj2 shar$						X	1
knowledge adj2 translat$						X	1
Knowledge adoption	X						1

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
Knowledge communication	X						1
Knowledge creation						X	1
Knowledge cycle	X						1
Knowledge development						X	1
Knowledge Development and Application	X						1
Knowledge diffusion	X						1
Knowledge dissemination	X						1
Knowledge exchange and uptake						X	1
Knowledge into use	X						1
Knowledge network?						X	1
Knowledge production	X						1
Knowledge production and utilization	X						1
Knowledge synthesis	X						1
Knowledge transformation	X						1
Knowledge utili#ation	X						1
link$ evidence						X	1
link$ practice						X	1
link$ research						X	1
link$ science						X	1
Mindlines	X						1
Motivation					X		1
Opinion leader	X						1
Participatory Research						X	1
Patient safety	X						1
policies adj2 develop$						X	1
policy and practice						X	1
Policy making						X	1
Popularization of research	X						1

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
practice adj2 chang$						X	1
Practice based evidence						X	1
Product adoption and utilization	X						1
program$ adj3 adopt$						X	1
Quality assurance, Health Care	X						1
research adj2 "use"						X	1
research adj2 aware$						X	1
research adj2 diffusion					X		1
research adj2 disseminat$						X	1
research adj2 impact$						X	1
research adj2 transfer$						X	1
research adj2 uptak$						X	1
Research capacity	X						1
Research implementation	X						1
Research integration	X						1
Research Practice Gap	X						1
Research utili#ation	X						1
return on investment						X	1
Routinization	X						1
science adj2 aware$						X	1
science adj2 impact$						X	1
science adj2 implement$						X	1
science adj2 uptak$						X	1
science adj2 utilizat$						X	1
Science communication	X						1
Science evidence						X	1
Self Efficacy					X		1

K* Term	KT Wiki	LaRocca	McKibbon	Mitton	Scott	Van Eerd	Count
Sociology of Knowledge	X						1
Spread	X						1
Sustainability	X						1
Technology transfer						X	1
Third Mission	X						1
Transfer	X						1
Translating research into practice	X						1
Translation	X						1
Translational medicine	X						1
Translational research phase I	X						1
Translational research phase II	X						1
Translational research phase III	X						1
Translational science	X						1
Transmission of knowledge	X						1
TRIP	X						1
Turning research into practice	X						1
validation	X						1

Paper 1 Additional File 4: MEDLINE Search Strategy
Ovid Medline (R)
1990 to January week 2 2015
Searched on 21 January 2015
530 records were retrieved (after duplicates removed)

CONCEPT 1: Social Network Analysis

Line	Search terms	Article retrieved
1	((social network$) adj3 (analy$ method or analy$ technique$ or analy$ or approach or data$ or diagram$ or examin$ or explor$ or framework$ or indicator$ or information or inquiry or interaction$ or investigat$ or intervention$ or map$ or measure$ or method$ or metric or model or pattern or perspective$ or questionnaire$ or software or structure$ or survey$ or technique$ or theor$ or tool$)).ti,ab.	1627
2	Network intervention$. ti,ab.	77
3	Exp Interprofessional Relations/	56072
4	(network or networks) .ti, ab	214954
5	3 and 4	1203
6	exp Sociometric techniques/	1062
7	(sociometr$ or sociogram$ or sociomap$ or network structure).ti,ab.	2825
8	(opinion leader$ or change agent$ or champion$ or knowledge broker$).tw.	4547
9	5 and (6 or 7 or 8)	34
10	(UCINET or NetDraw or KrackPlot or NetMiner or StOCNET or GRADAP or NEGOPY or FATCAT or MultiNet or Agna or Blue Spider or DyNet or MDLogix Solutions or Network Workbench or Pajek or Sentinel Visualizer or SocNetV or visone or CID-ABM or C-IKNOW or Commetrix or MetaSight or Referral Web or SONIVIS or CiteSpace or E-Net or Ego Net or VennMaker or Financial Network Analyzer or PGRAPH or PermNet or CFinder or KeyPlayer or KliqFinder or Network Genie or ONA surveys or NodeXL or MatMan or yFiles or LibSNA or NetworkX or UrlNet or igraph or latentnet or RSiena or statnet or tnet).tw.	117
11	1 or 2 or 9 or 10	1780

CONCEPT 2: Diffusion of Innovations

Line	Search terms	Article retrieved
12	exp diffusion of innovation/	15787
13	Diffusion of innovation$.tw.	447
14	((diffusion or diffusivity) adj3 (characteristic$ or evidence or information or innovation or innovation adaptation or innovation adoption or knowledge or mapS or measurementS or modelS or pathway$ or pattern$ or process$ or propert$ or simulation$ or strateg$ or stud$ or system$ or technique$ or theor$ or theory model$)).ti,ab.	16396
15	((Innovation adj1(adopt$ or implementation or adaptation or development process or sharing or exchange)) or (Program adopt$ or (innovation$ in service delivery and organi#ation) or (innovation adoption and diffusion))) .ti,ab.	253
16	Innovation adj2 (adopt$ or implement$)	252
17	12 or 13 or 14 or 15 or 16	32026

CONCEPT 3: Knowledge Translation/Transfer

Line	Search terms	Article retrieved
18	exp organizational innovation/ or exp continuing education/ or exp policy/ or exp quality improvement/ or exp Total Quality Management/ or exp Knowledge management/ or exp evidence-based practice/ or exp evidence-based medicine/or exp Health Services Research/mt	276358
19	(action research or adoption or applied dissemination or best practi?e or change or communit$ of practi?e or complex intervention or dissemination or effective dissemination or evaluation or guideline implementation or implementation or implementation research or implementation science or information or innovation or institutionali#ation or (linkage and exchange) or Participatory Action Research or policies or policy research or service innovation or translational research or “use” or utili#ation).ti,ab.	1663002
20	(integrated knowledge translation or knowledge mobili#ation or knowledge to action or transmission of knowledge or knowledge network? or sharing knowledge).ti,ab.	854
21	(knowledge adj2 (utili#? or uptake or transfer$ or disseminati$ or diffusi$ or translat$ or broker$ or exchange or generation or integration)).ti,ab.	4387
22	((Evidence adj2(exchange or transfer or uptake or diffus$ or implement$ or translat$ or utili#?)) or ((research adj2 (implement$ or transl$ or utili#?))).ti,ab.	11872
23	((information adj1(dissemination or exchange or transfer$ or transl$)) or ((data adj1(exchange or transfer or transl$))).ti,ab.	6935
24	18 or 19 or 20 or 21 or 22 or 23	1887679

Compilation

Line	Search terms	Article retrieved
25	11 and 24	625
26	11 and 17	39
27	25 or 26	630
28	animals.sh	5354095
29	27 not 28	585
30	limit 29 to (English language and yr="1990 -Current")	536
	Duplicates	6
	Final	530

Key
/ = indexing term (MeSH heading)
exp = exploded MeSH heading
$ = truncation
? = optional character
.ti,ab. = terms in either title or abstract fields
adj3 = terms within three words of each other (any order)
.sh.= subject heading field
tw = text word

Paper 1 Additional File 5: Critical Appraisal Tool for Qualitative Studies

Critical appraisal for qualitative study (or study component)		Reviewer 1		Reviewer 2		Reconciliation	
	Theoretical Approach	**Yes/No/Unclear**	**Comments**	**Yes/No/Unclear**	**Comments**	**Yes/No/Unclear**	**Comments**
1	Is a qualitative approach appropriate? (yes= research question sought to understand processes, structure or illuminate subjective experiences or meanings)						
2	Were the research aims/objectives/ research questions clearly stated?						
3	Were the values/assumptions/theory underpinning the study design approach discussed and justified? (look for: grounded theory, discourse analysis, ethnography, phenomenology, content analysis)						
	Study design						
4	Was the research design/methodology rigorous? (were the methods clearly linked to the theory/research question? was there a clear rationale/justification for the setting? Was participant recruitment method discussed (face to face, telephone, e-mail, mail, etc)? Was sampling strategy clear and justified (purposive, convenience, consecutive, snowball)? Was the data collection method well described (setting, individuals present)? Was there an "audit trail"? Were the analysis techniques appropriate and well described?)						
5	Were there adequate number of participants? Were any refusals or drop outs reported? Were reasons given and reported?						
	Data Collection						
6	Are the data collection methods clearly described? (tools provided, were the methods/tools piloted? If they changed over time was this evolution described and justified? form of data collected clear i.e. field notes, audio/video recordings, etc)						
7	Were the data collected appropriate to address the research questions?						

Critical appraisal for qualitative study (or study component)		Reviewer 1		Reviewer 2		Reconciliation	
	Theoretical Approach	**Yes/No/Unclear**	**Comments**	**Yes/No/Unclear**	**Comments**	**Yes/No/Unclear**	**Comments**
8	Was the observation period/data collection period adequate? (did the author discuss saturation?)						
	Validity						
9	Is the study setting and context clearly described?						
10	Was context bias considered? (did the authors consider the influence of the setting where the study took place?)						
11	Were the methods reliable? (used in previous studies for similar purpose, were there efforts to address data quality, i.e.triangulate data, respondent validation, repeat interviews)						
	Analysis						
12	Are the data "rich"? (yes= clear level of detail, diverity of perspective and content explored, responses compared/contrasted across groups, etc)						
13	Is the analysis reliable? (Yes= more than one researcher coded transcripts/data, description of how differences were resolved, clear how themes/concepts were derived from the data, role of the researcher and their potential bias and influence through the study considered (reflexivity), relationship between the researcher and participants described and considered, respondent validation verified findings)						
14	Are the findings clearly presented? If sufficient data presented to support the findings? Are data that contradict the findings discussed and presented?						
15	Are extracts from the original data included (direct quotes from participants)						
	Conclusions						
16	Is there a clear link between research question, theory, data, interpretation and conclusions?						

Critical appraisal for qualitative study (or study component)		Reviewer 1		Reviewer 2		Reconciliation	
	Theoretical Approach	**Yes/No/Unclear**	**Comments**	**Yes/No/Unclear**	**Comments**	**Yes/No/Unclear**	**Comments**
17	Have alternative explanations been explored and discounted?						
18	Were other studies with similar/different results discussed?						
19	Are the implications of the research clearly identified? (Is generalisability/external validity discussed?) Are future directions for research discussed?						
20	Is there discussion of study limitations?						
	Ethics						
21	Was the study approved by an ethics committee?						
22	Has the relationship between the researcher and participants been described?						
23	Is how the research was explained and presented to the participants described?						
24	Is the funding source for the study clearly stated						
25	Were researcher qualifications/credentials given?						
	Overall assessment of study quality						
	Note: High quality (++): Majority of criteria met. Little or no risk of bias. Results unlikely to be changed by further research (rough guidance-- "yes" for 75% of 25 question categories). Acceptable (+): Most criteria met. Some flaws in the study with an associated risk of bias, Conclusions may change in the light of further studies. (rough guidance-- "yes" for 50-75% of 25 question categories) Low quality (0): Either most criteria not met, or significant flaws relating to key aspects of study design. Conclusions likely to change in the light of further studies. (rough guidance-- "yes" for 25-50% of 25 question categories) Keep in mind not all questions are equally valuable to assessing quality.	++/+/0		++/+/0		++/+/0	

Paper 1 Additional File 6: Critical Appraisal Tool for Quantitative Studies

Critical appraisal of quantitiative study (or study component)		Reviewer 1		Reviewer 2		Reconciliation	
	Theoretical Approach	**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**
1	Was the scientific background and rational for the study given?						
2	Were the research aims/objectives/research questions/hypotheses clearly stated?						
3	Was the theory underpinning the study design discussed?						
	Methods						
4	Is the research design/methodology rigorous and focused? (clear rationale/justification for the sampling, data collection and analysis techniques)						
5	Were the methods and data collected appropriate to address the research questions?						
6	Was an explanation given for how the study size was determined? (was there a power calculation, if relevant)						
7	Were all important outcomes, exposures, predictors, potential confounders, effect modifiers clearly decribed as well as their sources and data collection methods (including characteristics of study participants)?						

Critical appraisal of quantitiative study (or study component)			Reviewer 1		Reviewer 2		Reconciliation	
	Theoretical Approach		**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**
8	Was selection of study participants rigorous?							
		Cohort: Were eligibility criteria, sources, methods and timing of recruitment and follow up described? Was the cohort representative of a defined population? If matched, was matching criteria described and numbers of exposed/unexposed given? Were response/participation rates given for each group and were the groups otherwise comparable other than the factor under investigation?						
		Case-control: Were eligibility criteria, sources, methods and timing of case ascertainment and control selection described? Was the rationale for the choice of cases and controls given? Were the cases/controls representative of a defined population (geographically/temporally)? Were participation rates give for both cases and controls? If matched, was matching criteria and number of controls per case given? Were the same exclusion criteria used for cases and controls? Was it clearly established that controls are non-cases?						
		Cross-Sectional: Were eligibility criteria, and the sources, methods and timing of selection of participants described?						

Critical appraisal of quantitiative study (or study component)		Reviewer 1		Reviewer 2		Reconciliation	
	Theoretical Approach	**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**
9	Were efforts made to reduce bias during data collection (i.e. selection bias, missing data procedures, blinding where appropriate, use of validated tools, objective tools where possible, etc)?						
	Cohort: was loss to follow up addressed? (i.e. were analyses done to see if those lost were systematically different than those who remained in the cohort?) Were all subjects classified into exposure/outcome groups using the same procedure? Was this assessment carried out more than once (if applicable)						
	Case-control: did matching efforts consider bias? Was non-response high? Could there be a systematic difference between cases and controls due to response rates?						
	Cross-Sectional: was the sampling strategy developed with the intention of reducing bias?						
10	Was the study duration long enough to observe the effect, was response rate/ follow up throughout sufficient?						
	Results						
11	Are the findings clearly presented? (indicate number of participants with missing data for each variable of interest, where appropriate was the study free of selective reporting, contamination, did they report unadjusted and clearly described adjusted estimates, clear description of category boundaries for categorized continuous variables)						
12	Were appropriate analyses conducted to take account of possible sources of bias? (look for modelling, stratification, subgroup analyses, regression, and/or sensitivity analyses to correct, control or adjust for confounding factors)						

Critical appraisal of quantitative study (or study component)		Reviewer 1		Reviewer 2		Reconciliation	
	Theoretical Approach	**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**
13	Are the results valid/precise/believable?						
	Cohort: Are the results precise (were confidence intervals reported? how wide are they?), Consider the association between exposure and outcome (RR), what is the absolute risk reduction (ARR)? Have they reported the rate or proportion between exposed/unexposed, the ratio/rate differences? Do you believe the results (considering effect size, statistical power of the study, likelihood due to chance, bias or confounding, study design flaws)						
	Case-control: Are the results precise? (were confidence intervals provided? Consider size of confidence interval, size of p value, variables considered, effect of missing data) Do you believe them?(consider size of the effect (OR), likelihood due to chance or confounding, study design flaws)						
	Cross-sectional: Are the results precise? (consider sampling, data collected and analyses conducted) Do you believe them? (considering study design flaws, efforts made to minimize bias)						
	SNA						
14	Are network boundaries clearly defined and appropriate for the research questions?						
15	Are appropriate SNA metrics selected, well defined, their calculation described and their level of analysis appropriate (actor-level, network level, subgroup level)?						
16	Response rates given for whole network studies? (If necessary, were there appropriate caveats in interpreting certain SNA metrics if missing data)						
17	Clear definition of tie relationships, direction and strength?						
	Discussion						
18	Is there a clear link between data, interpretation and conclusions?						

Critical appraisal of quantitative study (or study component)		Reviewer 1		Reviewer 2		Reconciliation	
	Theoretical Approach	**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**	**Yes/No/ Unclear**	**Comments**
19	Have alternative explanations been explored and discounted?						
20	Were other studies with similar/different results discussed?						
21	Are the implications (both to the local population and the generalisability/external validity) of the research discussed?						
22	Is there discussion of study limitations? (sources of bias/imprecision, direction and magnitude of any potential bias)						
	Other						
23	Was the study approved by an ethics committee?						
24	Is the funding source for the study clearly stated?						
	Overall Assessment of Study Quality						
	How well has the study done to minimize the risk of bias (selection bias, performance bias, attrition bias, detection bias, as appropriate to study design) or confounding?	++/+/0					
	Note: High quality (++): Majority of criteria met. Little or no risk of bias. Results unlikely to be changed by further research (rough guidance-- "yes" for 75% of 25 question categories). Acceptable (+): Most criteria met. Some flaws in the study with an associated risk of bias, Conclusions may change in the light of further studies. (rough guidance-- "yes" for 50-75% of 25 question categories) Low quality (0): Either most criteria not met, or significant flaws relating to key aspects of study design. Conclusions likely to change in the light of further studies. (rough guidance-- "yes" for 25-50% of 25 question categories) Keep in mind not all questions are equally valuable to assessing quality.						

Paper 1 Additional File 7: Data Extraction Tool

Data Extraction Tool

Information to extract	Reviewer 1		Reviewer 2		Reconciliation	
	Extraction	Comments	Extraction	Comments	Extraction	Comments
ID Number						
DOI Number						
Title						
Authors						
Publication Date						
Type of Publication (journal article, report, etc)						
Name of Publication (journal name/website, etc)						
Setting (Country/Countries)						
Health system level (PHC, district, …)						
Health area						
Health intervention/innovation						
Type of Health Care Worker population (i.e. nurses or non-physician clinicians)						
Number of health care workers included in study						
Patient population (if specific)						
Patient outcomes captured						
Study objective/ focus of network study (networks captured)						
Study design (observational/experimental/longitudinal/cross-sectional, etc)						
Study duration (length of data collection period)						
Study timeframe (time frame data collected covers)						
Unit of analysis						
Research question(s)						

Information to extract	Reviewer 1		Reviewer 2		Reconciliation	
	Extraction	Comments	Extraction	Comments	Extraction	Comments
Social network analysis methods						
Data collection method						
Boundary specification method/ sampling (if applicable)						
Network category studied (whole network/egocentric network)						
Response rate						
Network metrics used						
Software						
Network map (Yes/No)						
Results/conclusion						
Recommendations for further research						
Network intervention (yes/no)						
Policy change or research implications						
Study limitations						

Paper 1 Additional File 8: Existing SNA Systematic Reviews

Systematic Review	Year	Focus of review	Languages	Databases	Search dates	Studies	Recommendations for further research	Recommend Network interventions?
Mitchell *et al.*	2016	Social network studies set in long-term care (LTC), including residents with dementia, and identify network factors influencing the care available to residents. Studies included those examining social networks of residents or staff in LTC. (not just HCWs)	English	(7)CINAHL, EMBASE, IBSS, Medline, PsychInfo, Scopus, and Web of Science	1994 - December 2014	6 studies (9 articles 4 on staff)	Further research into network structures could investigate how social networks improve staff's workplace experience, enable better care for residents, and contribute to organizational success in a constantly changing environment. Studies could incorporate longitudinal studies and those with a control group. Statistically significant numbers are also needed. Research also could be done not just at the actor level, but could investigate interorganization networks in this sector and their effect on care outcomes.	
Bae *et al.*	2015	This review identified and described studies reporting results of an SNA undertaken in a health care setting and assessed factors contributing to social network, the role and influence of social networks in a health care setting (limited to health facilities), and the relation to how the features of networks may improve care processes and patient safety outcomes.	English	(7) CINAHL, Cochrane Database of Systematic Reviews,PubMed, PsycINFO, JSTOR, Medline(OVID), and Web of Science.	up to April 2013	28 studies (29 articles) 25 Quant only 3 Mixed methods	relatively few studies examined the relationships between social network and care process/ patient safety outcomes.	
Benton *et al.*	2015	To explore the use of social network analysis involving nurses either as subjects of the study or as researchers.	English, Spanish, Portuguese	(3) CINAHL, SciELO and PubMed plus Google, Yahoo	1965 - December 2013	43	The lack of longitudinal studies and the absence of replication across multiple sites should be seen as an opportunity for further research.	

Systematic Review	Year	Focus of review	Languages	Databases	Search dates	Studies	Recommendations for further research	Recommend Network interventions?
Perkins et al.	2015	Research questions: How are sociocentric social networks quantitatively measured in LMICs for health-related research? 2. What common observations can we make about how network composition, network position, and network structure are associated with health and health behaviors in these settings? 3. How can sociocentric network data collection be improved in LMICs and what directions might future research on social networks and health in LMICs take? Selection criteria: (a) used quantitative data collected via census-based inclusion of participants (b) enumerated a sociocentric social network within a circumscribed boundary by identifying specific person-to-person or household-to-household ties through a name-generation method in a defined population; and (c) provided a description of sociocentric network data collection methods, calculated some sort of network measure (either at the level of the individual, such as centrality, or at the level of the whole network, such as the number of components), or provided a map of a complete social network.	English	(4) PubMed, Econlit, Sociological Abstracts, and PsychINFO	through Dec 2013	10 unique studies (17 articles)	"there is a strong need for more in-depth sociocentric network and health studies in LMICs, particularly in relation to intervention and evaluation, using standardized metrics." despite the potential richness of sociocentric network data, analyses have not progressed beyond basic calculations, particularly for studies conducted in LMICs.longitudinal data and experiments are needed to increase understanding of pathways and causality. The associations between network characteristics and individual outcomes demonstrated by many extant studies using observational data are subject to all the usual sorts of constraints affecting observational studies . Ongoing development of tools for faster and more accurate network data collection	

Systematic Review	Year	Focus of review	Languages	Databases	Search dates	Studies	Recommendations for further research	Recommend Network interventions?
Long et al.	2013	The aim of this review is to systematically review the empirical, peer reviewed research on bridges, brokers and boundary spanners from a network theoretical perspective, across a wide range of collaborative settings in order to inform our understanding of brokerage in networks. (not specific to health)	English	(4) Medline, CINAHL, Business Source Premier (BSP), and the International Bibliography of Social Sciences (IBSS).	1994 - 2011	24	This strategy of identifying bridges could be used across healthcare settings to enhance uptake of new practice guidelines or other initiatives needing to be disseminated widely and has a different focus from similar work looking at the role of opinion leaders in this process. There is also the potential for research identifying bottlenecks in communication flows or instances of information hoarding or inappropriate gatekeeping. Future research on the enactment of brokerage roles in specific healthcare contexts [4,15] and evaluating interventions to support or introduce brokers will further inform this promising area.	YES
Chambers et al.	2012	Our primary objective was to evaluate the use of SNA as part of an intervention to support the implementation of change in healthcare organisations. A secondary objective was to identify and describe studies that report the results of an SNA undertaken in a healthcare setting: and attempt to assess what they tell us about the role and influence of social networks in healthcare organisations.	not restricted	(10) MEDLINE, EMBASE; PsycINFO; HMIC, the Cochrane Librarys, CINAHL; Business Source Premier; Social Science Citation Index; Conference Proceedings Citation Index; ASSIA.	1950 - October 2011	52 studies	Future research should seek to go beyond the merely descriptive to implement and evaluate SNA-based interventions.Future studies involving SNA in healthcare should be designed with an intervention and comparator. SNAs can be either dependent or independent variables not divorced from any other intervention (independent variable) or measurement (dependent variable). unclear to what extent the studies included in our review used theory to guide their exploration and analysis of healthcare social networks.	YES

Systematic Review	Year	Focus of review	Languages	Databases	Search dates	Studies	Recommendations for further research	Recommend Network interventions?
Cunningham et al.	2012	studied the structure of networks of health care professionals and the effectiveness and sustainability of networks on quality of care and patient safety.	English	(6) MEDLINE, CINAHL, EMBASE, Web of Science and Business Source Premier	1995- Dec 2009	26		
Flodgren et al.	2011	To assess the effectiveness of the use of local opinion leaders in improving professional practice and patient outcomes. (limited to RCTs)	not restricted	(9) Cochrane EPOC Group Trials Register, the Cochrane Central Register of Controlled Trials, MEDLINE, EMBASE, HMIC, Science Citation Index, Social Science Citation Index, ISI Conference Proceedings and World Cat Dissertations	up to 5 May 2009	18 RCTs	Cost and cost effectiveness of opinion leader interventions. More research on methods of identifying opinion leaders and contexts where opinion leaders are most effective	Yes
Dunn et al.	2011	studied network structure from observation-based case studies as a comparison of observed network patterns against a priori gold standard criteria.	English	(1) Medline	2005 and May 2010	3 case studies	We propose that future case studies involving social network analysis in healthcare organisations would benefit from the application of this validation method	
Braithwrite et al.	2010	Review literature on social spaces, holes, gaps, boundaries and edges	English	(5)ABI/INFORM Global, CINAHL, IBSS, Medline and Psychinfo	through -Dec 2009	13	none stated	

Paper 1 Additional File 9: PRISMA Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	**1**
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	**2**
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	**4**
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	**5**
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	**Abstract & p. 6**
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	**6**
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	**5**
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	**Additional file 4**
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	**p. 6-7**
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	**p. 7, Additional file 7**
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	**additional file 7**
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	**p.6-7, Additional files 5-6**
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	**Tables 2-6**

Section/topic	#	Checklist item	Reported on page #
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	**p. 6-7**
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	**p.6, p.13 and additional files 5-7**
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	**N/A**
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	**Figure 1**
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	**Table 1**
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	**Tables 2 & 5**
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	**Tables 2 & 5**
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	N/A
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	**Table 2**
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	**7-11, Tables 2-6**
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	**12**
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	**13**
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	**14**

12.2 Annex 2: Network Study Ethics Approval-Ethiopia

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የሳይንስና ቴክኖሎጂ ሚኒስቴር
The Federal Democratic Republic of Ethiopia
Ministry of Science and Technology

ቁጥር 3·10/060/2015
Ref. No.
ቀን Oct 26, 2015
Date

To: JaRco consulting
Addis Ababa

Re: Qualitative study about how health professionals at health center and health post seek advice

Dear Sir/Madam//Mr./Mrs./Dr,

The National Research Ethics Review Committee (NRERC) has reviewed the aforementioned project protocol in an expedited manner. We are writing to advise you that NRERC has granted

Full Approval

To the above named project, for a period of **one year (October 26, 2015- October 25, 2016).** All your most recently submitted documents have been approved for use in this study. The study should comply with the standard international and national scientific and ethical guidelines. Any change to the approved protocol or consent material must be reviewed and approved through the amendment process prior to its implementation. In addition, any adverse or unanticipated events should be reported within 24-48 hours to the NRERC. Please ensure that you submit biannual progress report once in six months and annual renewal application 30 days prior to the expiry date.

We, therefore, request you as PI and your esteemed organization to ensure the commencement and conduct of the study accordingly and wish for the successful completion of the project.

With regards,

[redacted] **Sitotaw**
Secretary of NRERC

Chairperson, NRERC

Mr. Tsegahun Tessema (PI)

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You may Contact

ፖ.ሳ.ቁ. አዲስ አበባ ኢትዮጵያ ስልክ ፋክስ

12.3 Annex 3: Network Study Ethics Approval letter--LSHTM

London School of Hygiene & Tropical Medicine
Keppel Street, London WC1E 7HT
United Kingdom
Switchboard: +44 (0)20 7636 8636

www.lshtm.ac.uk

Observational / Interventions Research Ethics Committee

LSHTM

24 August 2015 24 August 2015

Dear ,

Study Title: Professional advice networks of community-based health workers in Ethiopia

LSHTM ethics ref: 10128

Thank you for your application for the above research, which has now been considered by the Observational Committee.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

Conditions of the favourable opinion

Approval is dependent on local ethical approval having been received, where relevant.

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document Type	File Name	Date	Version
Protocol / Proposal	PAS Protocol v2.0	29/04/2015	2.0
Information Sheet	Participant Information Sheets and Informed Consent Forms	15/06/2015	1.0
Investigator CV	Researcher CVs	16/06/2015	1.0
Covering Letter	Cover Letter 7 July 2015	07/07/2015	1.0

After ethical review

The Chief Investigator (CI) or delegate is responsible for informing the ethics committee of any subsequent changes to the application. These must be submitted to the Committee for review using an Amendment form. Amendments must not be initiated before receipt of written favourable opinion from the committee.

The CI or delegate is also required to notify the ethics committee of any protocol violations and/or Suspected Unexpected Serious Adverse Reactions (SUSARs) which occur during the project by submitting a Serious Adverse Event form.

At the end of the study, the CI or delegate must notify the committee using an End of Study form.

All aforementioned forms are available on the ethics online applications website and can only be submitted to the committee via the website at: http://leo.lshtm.ac.uk

Additional information is available at: www.lshtm.ac.uk/ethics

Yours sincerely,

[redacted]

Professor John DH Porter
Chair

ethics@lshtm.ac.uk
http://www.lshtm.ac.uk/ethics/

12.4 Annex 4: Roster Generator

PHCU Roster Generator Tool **PHCU CODE**

Enumerator _____ Date _____

Region _____ Health Post Names: _____ _____

Zone _____ _____ _____

Woreda _____ _____ _____

Health Center: _____ _____ _____

Health posts: _____ _____ _____

When did CBNC training happen?

Have there been any mentorship programs in the last year?

Describe:

Have there been any major staffing changes in the last year?

Describe:

#	Name of Health Care Worker	Health Facility	Cadre	Mobile Number
1				
2				
3				
4				
5				
6				
7				
8				
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26				
27				
28				
29				
30				

12.5 Annex 5: Network data Tool

Enumerator Name: Date: Start time: End time: Individual Code:

Attributes

Name **Cadre** **Region**

Age **Total Years of experience** **Woreda**

Gender **Years at this health facility** **Health Facility**

Ask HEW only: **Have you received training on CBNC? Yes/ No If yes, Date CBNC training conducted (mm/yy)**

Ask non-HEW only: **Have you received an orientation to CBNC? Yes/ No If yes, Date CBNC orientation conducted (mm/yy)**

Antenatal Care Advice Network Question — Frequency

In the last year, who on this list came to you for advice on providing antenatal care?
Show them the roster
How frequently did they come to you for advice on providing antenatal care?

Roster Number	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5

Is there anyone not on this list who came to you for advice on providing antenatal care in the last year?
What is their name, occupation and where do they work?
How frequently did they come to you for advice on providing antenatal care?

Name	Occupation	Place of work/ Community	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5

Antenatal Care Advice Network Question — Frequency — Individual Code

In the last year, who on this list did you go to for advice on providing antenatal care?
Show them the roster
How frequently did you go to them for such advice?

Roster Number	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5

Is there anyone not on this list who you went to for advice on providing antenatal care in the last year?
What is their name, occupation and where do they work?
How frequently did you go to them for advice on providing antenatal care?

Name	Occupation	Place of work/ Community	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5
_____	_____	_____	0	1	2	3	4	5

Delivery Care Advice Network Question			Frequency			Individual Code
In the last year, who on this list came to you for advice on providing delivery care? *Show them the roster* **How frequently did they come to you for advice on providing delivery care?**	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
Roster Number						
_____	0	1	2	3	4	5

Postnatal Care Advice Network Question			Frequency			Individual Code
In the last year, who on this list came to you for advice on providing postnatal care? *Show them the roster* **How frequently did they come to you for advice on providing postnatal care?**	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
Roster Number						
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5

Is there anyone not on this list who came to you for advice on providing postnatal care in the last year? **What is their name, occupation and where do they work?** **How frequently did they come to you for advice on providing postnatal care?**	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
Name / Occupation / Place of work/ Community						
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5

Postnatal Care Advice Network Question			Frequency			Individual Code
In the last year, who on this list have you gone to you for advice on providing postnatal care? *Show them the roster* **How frequently have you gone to them for such advice?**	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
Roster Number						
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5

Is there anyone not on this list who you went to for advice on providing postnatal care in the last year? **What is their name, occupation and where do they work?** **How frequently did you go to them for advice on providing postnatal care?**	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
Name / Occupation / Place of work/ Community						
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5

Newborn Care Advice Network Question			Frequency			Individual Code
In the last year, who on this list came to you for advice on providing newborn care? *Show them the roster* **How frequently did they come to you for advice on providing newborn care?**	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
Roster Number _____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5

Is there anyone not on this list who came to you for advice on providing newborn care in the last year? **What is their name, occupation and where do they work?** **How frequently did they come to you for advice on providing newborn care?**	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
Name _____ Occupation _____ Place of work/ Community _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5

Newborn Care Advice Network Question			Frequency			Individual Code
In the last year, who on this list did you go to for advice on providing newborn care? *Show them the roster* **How frequently did you go to them for such advice?**	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
Roster Number _____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5
_____	0	1	2	3	4	5

Is there anyone not on this list who you went to for advice on providing newborn care in the last year? **What is their name, occupation and where do they work?** **How frequently did you go to them for advice on providing newborn care?**	No Contact	Semi-annually	Quarterly	Monthly	Weekly	Daily
Name _____ Occupation _____ Place of work/ Community _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5
_____ _____ _____	0	1	2	3	4	5

12.6 Annex 6: Health Service Coverage Data Tool at Health Posts

Enumerator Name: Date:_____ **Facility Code:_____**

Individual Code:_____

GPS Coordinates Latitude:_____ Longitude:_____

MODULE 3: HEALTH POST REGISTER REVIEW BY THE DATA COLLECTOR			
INTERVIEWER: FOR QUESTION HP3.1 TO HP 3.4 COLLECT INFORMATION FOR THE LAST YEAR. FOR QUESTIONS 3.5 TO THE END COLLECT INFORMATION ON THE LAST THREE MONTHS ON SERVICES PROVIDED BY THE HEALTH POST. **PLEASE LOOK AT THE SPECIFIED HEW REGISTERS DETAILED BELOW FOR THE DIFFERENT DATA ELEMENTS.** **WRITE 9999,999 OR 99 IF NOT AVAILABLE.** ***I would now like to take a look at your registers to abstract information about the community in this kebele and the services provided them. I will ask about the population profile for the last 12 months and services provided by you for the last three months from _____ to _____.***			
Obtain data on population FOR THE YEAR from the day of survey from Health Post wall records			
HP3.1	Number of people in the kebele	|___|___|___|___| |	HP3.1
HP3.2	Number of households in the kebele	|___|___|___|___|	HP3.2
HP3.3	Total number of women of reproductive age	|___|___|___|___|	HP3.3
HP3.4	Total number of under 5 children in the kebele	|___|___|___|___|	HP3.4
Obtain data on expected number of pregnancies and births from the PAST QUARTER from Health Post wall records			
HP3.5	Expected number pregnancies	|___|___|	HP3.5
HP3.6	Expected number of births	|___|___|	HP3.6
HP3.7	Expected number of facility births	|___|___|	HP3.7
Obtain data from ANC registers for the PAST QUARTER			
HP3.8	Number of women receiving 1 visit	|___|___|	HP3.8
HP3.9	Number of women receiving 2 visits	|___|___|	HP3.9
HP3.10	Number of women receiving 3 visits	|___|___|	HP3.10
HP3.11	Number of women receiving 4 visits	|___|___|	HP3.11
Obtain data from delivery registers for the PAST QUARTER			
HP3.12	Number of births attended by the HEW	|___|___|	HP3.12
HP3.13	Number of total births (home, health post, health center, hospital)	|___|___|	HP3.13
HP3.14	Number of live births	|___|___|	HP3.14
HP3.15	Number of newborn deaths (28 days or less)	|___|___|	HP3.15
PNC data			
HP3.16	Is there a Post Natal Care register (standard or otherwise) in this health post	**1 = Yes** **2 = No**	HP3.16

If Post Natal Care register is not available but family folder is available, obtain the information from the family folder given for the PAST QUARTER. Ask the HEWs to separate those.			
HP3.17	Number receiving 1 visit	|___|___|	HP3.17
HP3.18	Number receiving 2 visits	|___|___|	HP3.18
HP3.19	Number receiving 3 visits	|___|___|	HP3.19
If information is not available from register books on the following, enquire from the HEW where to obtain the following information for the PAST QUARTER			
HP3.20	Number of newborns treated for asphyxia, initial stimulation, or resuscitation by the HEW	|___|___|	HP3.20
HP3.21	Number of newborns given chlorohexidine cord care by the HEW	|___|___|	HP3.21

12.7 Annex 7: Health Service Coverage Tool at Health Centre

Obtain data on expected number of pregnancies for the last quarter from MCH department wall records and ANC data from ANC register in MCH department	
HC5.1	Expected number of pregnancies in the health center catchment area in the last 3 months?
HC5.2	Number of women receiving 1st ANC visit at the health center
HC5.3	Number of women receiving 2nd ANC visit at the health center
HC5.4	Number of women receiving 3rd ANC visit at the health center
HC5.5	Number of women receiving 4th ANC visit at the health center
Obtain data on expected facility deliveries for the last quarter from MCH department wall records and delivery information from the delivery register in MCH department	
HC5.6	Expected number of facility births in the health center in the last three months?
HC5.7	Number of total deliveries in the health center
HC5.8	Number of live births in the health center
HC5.9	Number of still births in the health center
Obtain data for the following from PNC register in MCH department	
HC5.10	Number receiving 1st PNC visits for the mother at the health center
HC5.11	Number receiving 2nd PNC visits for the mother at the health center
HC5.12	Number receiving 3rd PNC visits for the mother at the health center
HC5.13	Number receiving 1st PNC visits for the child at the health center
HC5.14	Number receiving 2nd PNC visits for the child at the health center
HC5.15	Number receiving 3rd PNC visits for the child at the health center
HC5.16	Number of live births with birth weight <2500 grammes (or <2.5kg) in the health center
HC5.17	Number of newborns treated for asphyxia, - initial stimulation, or resuscitation in the health center
HC5.18	Number of pre-term and/or low birth weight neonates treated at the health center – Kangaroo-Mother-Care (KMC)

12.8 Annex 8: PHCU Cover Sheet for Quantitative Data Collection

PHCU Code: Region/Woreda/Health Centre:

Name of Supervisor Name of enumerators

Health Facilities:

	Facility Name	Health Facility Code	GPS Coordinates NORTH	GPS Coordinates EAST	Coverage Data Collected (tick if yes)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Interviews conducted:

	Health Facility code	Interviewee Name	Interviewee Code	Enumerator Initials	Date of data collection	Tick if recollected
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						

26						
27						
28						
29						
30						

Interviews not conducted of those on Roster and why:

	Individual Code	Reason not interviewed; document attempts to contact
1		
2		
3		

Name of those not on Roster (former employees, on study leave longer than 4 months)

Name	**Position**	**Facility**	**Date of Departure**	**Code (start with 50)**

Notes on data collection:

Checklist

Item in Folder	Tick if included
PHCU Cover sheet	
Rosters (3)	
Informed Consent sheets	
Completed Network data tools	
Completed HP Coverage data	

12.9 Annex 9: Selected PHCUs

PHCUs Selected for Quantitative Network Survey

Region	PHCU Code	ANC	PNC	Support Tally
1	A	Above	Average	Below
1	B	Below	Below	Average
2	C	replaced in the field, no previous data		
2	D	Below	Above	Below
3	E	Above	Above	Above
3	F	Above	Above	Average
4	G	Average	Below	Below
4	H	Below	Above	Below

PHCUs Selected for Qualitative Inquiry

PHCUs Selected for Qualitative Inquiry								
PHCU	Network data notes	Performance notes	Selection criteria data		Collected Performance Data			
					Health Post Average		Health Centre	
			ANC	PNC	ANC	PNC	ANC	PNC
PHCU A	least off roster advice seeking; standard volume of facilities	above?	73%	58%	65%	95%	100%	0%

PHCUs Selected for Qualitative Inquiry								
PHCU D	least ties , low out degree centrality, highest distance across 4 of the 7 networks	low?	14%	65%	58%	82%	28%	0%
PHCU E	most dense network across all networks, relatively high out degree centrality, lots of off roster advice seeking; fewer health facilities/HCWs	above?	70%	100%	135%	0%	100%	8%
PHCU G	most nodes with highest eigenvector centrality; outlier with few ties	unclear?	29%	14%	64%	88%	99%	100%

12.10 Annex 10: Individuals selected for Qualitative Inquiry by PHCU

PHCU A			
HCW Code	**Cadre**	**Facility**	**Notes on selection**
Selected:			
13	HEW	6	one of only two HEW engaging in off-roster advice exchange (two newest to PHCU); only at facility for 3 years ; trained in CBNC
5	MW	1	most advice giving engaging most people in PHCU, advice seeking off roster; highest betweeness, in degree centrality and eigenvector centrality
15	HO	1	most advice giving. Highest out degree centrality for ANC
12	HEW	6	most advice seeking considering frequency, second most individuals sought advice from; very experienced; highest out degree centrality for newborn network
7	HEW	2	very little advice seeking/giving; most experience (10yrs) experience and trained in CBNC
Backups:			
6	HEW	2	one of only two HEW engaging in off-roster advice exchange; only at facility for 1 year; not trained in CBNC
1	HO	1	most advice giving considering frequency
9	HEW	3	very little advice seeking/giving; average (6yr) experience and trained in CBNC
11	HEW	4	lots of advice exchange within PHCU
Guidance on order of replacement:			
If 15 or 5 not available, then 1; If no 7, then 9; If no 13, then 6; If no 12, then 11			
PHCU D			
HCW Code	**Cadre**	**Facility**	**Notes**
Selected:			
17	HEW	4	Most advice exchanging; only HEW engaged in off-roster advice exchange, 8 yrs experience, trained in CBNC
18	HEW	5	no advice exchange, not trained in CBNC, limited experience, only at facility for a year
11	MW	1	most advice exchanging among midwives, most individuals and most intensity highest betweeness for advice seeking, ANC, Maternity. Highest outdegree centrality for advice seeking, ANC. Highest in degree centrality for all networks. Highest eigenvector centrality for All, AS, AG, and newborn
5	Nurse	1	higher end of experience, most advice exchange of all-- most giving; orientated in CBNC. Highest betweeness overall, advice giving, PNC; Highest out degree centrality overall, advice giving, maternity and newborn. Highest eigenvector centrality for ANC, MAT and PNC
3	Nurse	1	most advice seeking; not orientated in CBNC; highest outdegree centrality for advice seeking
Backups:			
19	HEW	5	no advice exchange, not trained in CBNC, limited experience, only at facility for a year
10	MW	1	highest out degree centrality for advice seeking
13	HEW	2	second most advice exchanging of HEW
4	Nurse	1	a lot of advice giving, highest out degree centrality for newborn
7	Nurse	1	not a lot of experience, a fair amount of advice exchange. Highest out degree centrality for maternity
Guidance on order of replacement:			
If no 18, then 19; If no 11, then 10; If no 17, then 13; If no 5, then 4			

PHCU E			
HCW Code	**Cadre**	**Facility**	**Notes:**
Selected:			
13	HEW	3	only HEW not with off roster advice exchange, least advice exchange overall
10	HEW	2	HEW tied for most off roster advice exchange
15	NS	1	most advice giving among all, second for off roster; only HO had more
5	NS	1	most off roster advice giving, most advice seeking considering frequency
2	NS	1	average advice seeking/giving
Backups			
11	HEW	2	HEW tied for most off roster advice exchange
8	MW	1	
1	HO	1	
3	NS	1	
12	HEW	3	
Guidance on order of replacement:			
If no 13, then 12; if no 10, then 11; if no 15, then 1; if no 5, then 8; if no 2, then 3			

PHCU G			
HCW Code	**Cadre**	**Facility**	**Notes:**
Selected:			
4	MW	1	most advice exchanged, most giving
14	HEW	5	most advice seeking
16	HEW	4	least advice exchanged
3	HO	1	most advice exchanged for PNC/newborn
12	NS	1	most advice exchanged among nurses
Backups:			
17	HEW	3	most advice exchange among HEW
15	HEW	6	2nd least advice exchanged among HEW
1	HO	1	2nd most advice exchanged for PNC
10	NS	1	2nd most advice exchanged among nurses
7	MW	1	2nd most advice exchanged among MW
Guidance on order of replacement:			
If no 14, then 17; if no 16, then 15; If no 3, then 1; If no 12, then 10; If no 4, then 7			

12.11 Annex 11: PHCU Coversheet for Qualitative Inquiry

PHCU Coversheet
PHCU Code XX

Region: XX Zone: XX
Woreda: XX

Health Centre:XX

	Selected individuals			
tick	HCW Code	Facility	Cadre	Phone

	Replacements			
tick	HCW Code	Facility	Cadre	Phone

Tick above the individuals who were interviewed. Where replacements were used please describe in the space below the reason. If a replacement was used that was not listed above, please write in their information in the space provided. The bolded end of the code corresponds

Ask if there is a formal supervision structure in place. Ask if there are health centre staff assigned to supervise/mentor/support specific HEW or other more junior HC staff. Record below. Numbers correspond with Roster numbers

Does this HCW have a Supervisor?		
HCW Code		Yes/No

if Yes, supervisor code:
HCW Code

Notes:

PHCU Coversheet | Region: XX Zone: XX | Health Centre:XX

PHCU Code XX | Woreda: XX

Document any staff changes that have happened since the roster	
HCW Code	Date of departure

New staff

Cadre	Facility

12.12 Annex 12: Qualitative Interview Guide

Qualitative Interview Guide

Advice Seeking

1 In what situations do you go to another health care worker/colleague for advice related to maternal or newborn health?

Probes:

Ae you usually with a patient at the time, or is it after a visit?
What kind of advice are you usually asking for?
Who do you go to for advice?(show roster, document HCW code if not PHCU member, ask cadre and current working location) Why do you go to them for advice? How do you know them?

Are they usually able to provide advice, why or why not?
What happens if that person doesn't know the answer to your questions?
When and where does this advice exchange take place? Is it over the phone, e-mail or in person?

How often do you seek advice?
Are there reasons why you can't seek advice when you need to?
Do you feel like your needs for professional advice around maternal and newborn health are met? Why or why not?
Do you have someone you consider a mentor? Is this person an official supervisor or unofficial?

2 Tell me about the last time you went to someone for advice related to providing antenatal care?

3 Tell me about the last time you went to someone for advice related to providing delivery care?

4 Tell me about the last time you went to someone for advice related to providing postnatal care?

5 Tell me about the last time you went to someone for advice related to providing newborn care?

Probes (for 2-5):

Explore relationship with the individual from whom advice was sought recently-- when originally met, under what context, when did they first go to them for advice

Show roster, ask them to identify this person, note the HCW code. If not on roster, ask cadre, where they currently work
Ask type of advice, why you went to this person, ask if they were able to answer the question

When, where and through what communication route did this exchange take place

Advice Seeking

6 Who comes to you for advice related to providing maternal and newborn care?

Probes:

What kind of advice are they generally looking for related to maternal and newborn health?
Are you generally able to provide advice, why or why not?
What do you do if you do not know the answer?
When and where do people come to you for advice?
How often does this happen?

Are you a mentor for another healthcare worker? Is this an official or unofficial role?

7 Tell me about the last time someone came to you for advice related to providing antenatal care?

8 Tell me about the last time someone came to you for advice related to providing delivery care?

9 Tell me about the last time someone came to you for advice related to providing postnatal care?

10 Tell me about the last time someone came to you for advice related to providing newborn care?

Probes (for 6-10):

Explore relationship with the individual who came for advice recently-- when originally met, under what context, when did they first come for advice

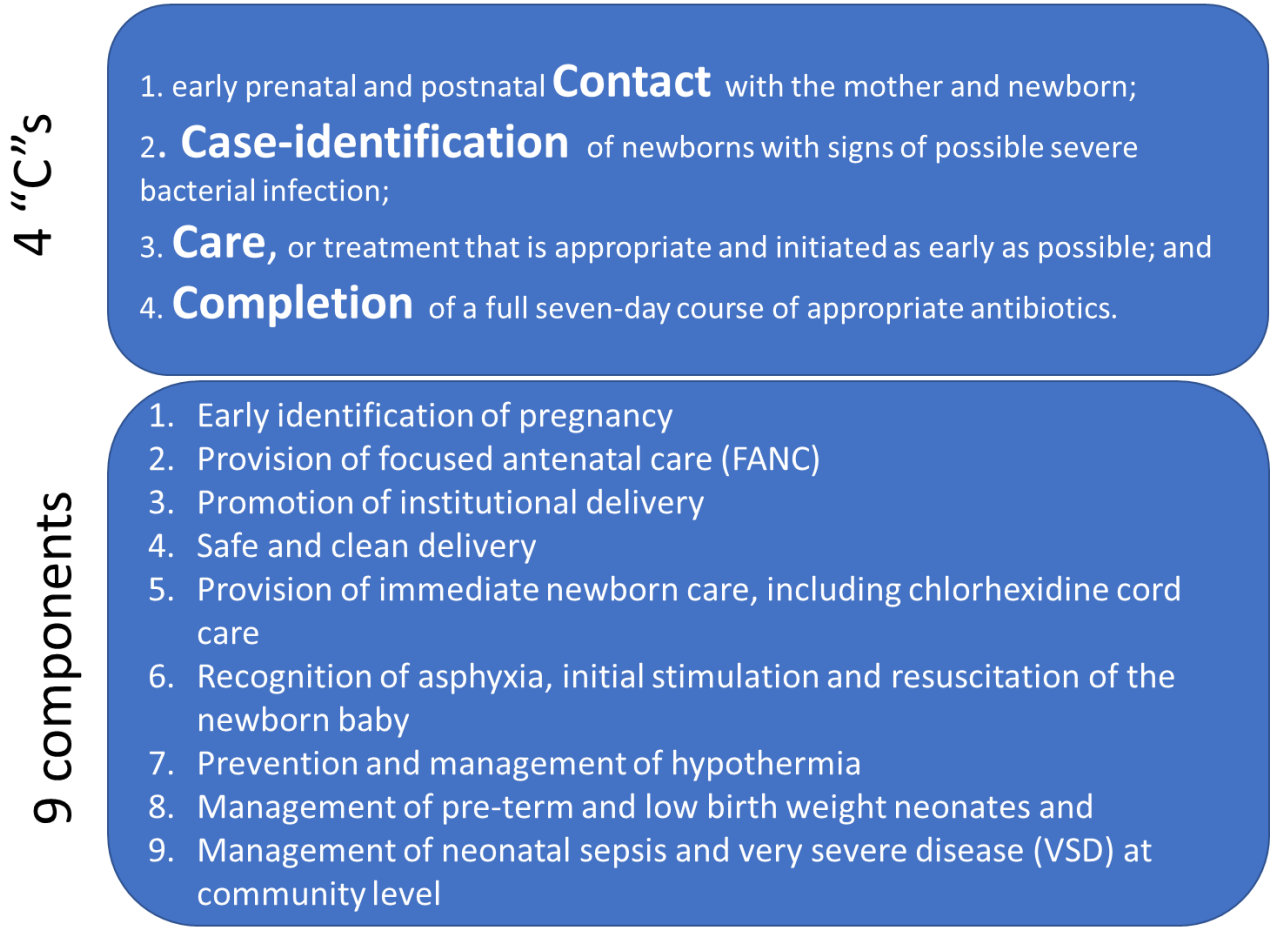
Show roster, ask them to identify this person, note the HCW code. If not on roster, ask cadre, where they currently work

Ask type of advice they sought, ask if they were able to answer the question

When, where and through what communication route did this exchange take place

12.13 Annex 13: Paper 2 Additional Files

Additional File 1: Community Based Newborn Care Framework



Additional File 2: Social Network Analysis Network Metric Definitions and Formulas			
Network Metric	Definiton	Calculation/Formula	UCINET
Actor- level			
Betweeness Centrality	The number of geodesic paths (the shortest path between two actors) that pass through a given actor.	There are different ways of calculating betweeness centrality, for our purposes we used Freeman's Betweeness Centrality. As described by Analytic technologies: "More precisely, if gij is the number of geodesic paths from i to j and gikj is the number of paths from i to j that pass through k, then gikj/gij is the proportion of geodesic paths from i to j that pass through k. The sum ck = gikj/gij for all i,j pairs is betweenness centrality. Normalized betweenness divides simple betweenness by its maximum value."	Network>Centrality and Power>Freemans Betweeness> Node Betweeness Output report look at actor with the highest value, report nBetweeness (normalized).
Out Degree	In a directed network, out degree centrality is the number or ratio of ties a given actor nominates, or initiates a direct relation towards another actor.	It can be expressed either as a whole number or a ratio. As a whole number it is the sum of outward directed ties to other actors. As a ratio, this sum is then divided by the total number of possible ties (n-1), the number of actors within the network, minus 1 (as the actor in question cannot have a tie with itself)	Network>Centrality>Degree Output report provides two tables. The first table provides actor level Out Degree centrality in first column, OutDegree as a whole number, and as a normalized percentage in the third column under NrmOutDegree

Network Metric	Definition	Calculation/Formula	UCINET
In Degree	In a directed network, in degree centrality is the number or ration of ties a given actor receives from other actors within the network	It can be expressed either as a whole number or a ratio. As a whole number it is the sum of all ties initiated from other actors. As a ratio, this sum is then divided by the total number of possible ties (n-1)	Network>Centrality>Degree Output report provides two tables. The first table provides actor level In Degree centrality in the second column, InDegree as a whole number, and as a normalized percentage in the fourth column under NrmInDegree
Eigenvector centrality	This is a weighted centrality metric. As with most centrality metrics it reflects the number of ties between an actor and the other actors within the network.	With Eigenvector centrality, the centrality of actors directly connected to the actor is taken into account. Those connected to more central actors have higher eigenvector centrality metrics. According to Analytic Technologies: Eigenvector centrality "is like recursive version of degree centrality: Start by assigning centrality score of 1 to all nodes (vi = 1 for all i), Recompute scores of each node as weighted sum of centralities of all nodes in a node's neighborhood: vi = xijvj, Normalize v by dividing each value by the largest value, Repeat steps ii and iii until values of v stop changing."	Network>centrality>eigenvector Output report node(s) with the highest values, as these are the nodes who along with their alters' ties are the most connected.

Network Metric	Definition	Calculation/Formula	UCINET
Network-level			
Centralization	Degree Centralization captures direct, or incident ties to other actors at the network level	It is expressed as a ratio or a percentage . To find network degree centralization, you must find the most central actor (C*). Then calculate the variation in degree centrality to the other network actors (Ci) *and sum the differences: Σ(C*-Ci), then divide this by the largest possible degree centralization, Max Σ(C*-Ci). Formula: Σ(C*-Ci) / Max Σ(C*-Ci) From UCSD ppt "network measures web"	Network>Centrality>Degree UCINET Report graph centralization scores at end of output
Out Degree Centralization	In a directed network, the ratio of ties actors nominate, or initiate towards other actors out of those possible	It is expressed as a ratio or percentage. All outward directed ties are summed, then divided by the total number of possible ties (the number of actors within the network)	Network>Centrality>Degree (old) UCINET Report Network centralization (outdegree) percentage for each matrix following the actor level table and the descriptive statistics table
In Degree Centralization	In a directed network, the ratio of ties actors receive from other actors out of those possible	It is expressed as a ratio or percentage. All inward directed ties are summed, then divided by the total number of possible ties (the number of actors within the network)	Network>Centrality>Degree (old)UCINET Report Network centralization (indegree) percentage for each matrix following the actor level table and the descriptive statistics table

Network Metric	Definition	Calculation/Formula	UCINET
Network-level			
Density	Density of a network is the total number of relational ties divided by the total possible number of relational ties.	total number of relational ties divided by the total possible number of relational ties d=L/ [n(n-1)/2], when L equals the actual number of ties (Prell p.167)	Network>Cohesion>Density (overall) Output report first column (density)
Number of Ties	Total number of ties between all actors in a network.	Sum of all ties between all actors (dichotomized)within a network	Network>Cohesion>Density (overall) Output report second column (No. of ties)
Distance	Length of optimal path between actors in a network	Average length of optimal path between actors in a network	Network>Cohesion>Geodesic Distances Output report average value
Isolates	An actor with no ties to other actors within the network	The number of actors without any ties for a given network are totalled	N/A

Additional File 3: Network level metrics grouped by PHCU									
PHCU	All networks (ALL)	All advice seeking networks (AS)	All advice giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All newborn care advice seeking or giving networks (Newborn)	descriptive statistics	
PHCU A	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
Degree Centrality	0.48	0.47	0.58	0.50	0.54	0.43	0.40	0.49	0.06
Out Degree	0.31	0.21	0.36	0.22	0.24	0.19	0.21	0.25	0.06
In Degree	0.54	0.56	0.18	0.57	0.53	0.43	0.27	0.44	0.157
Density	0.21	0.13	0.11	0.12	0.11	0.09	0.08	0.12	0.043
No. ties	71	45	36	42	37	32	26	41.29	14.51
Distance	2	2.1	1.5	2.3	2.1	2.1	1.8	1.99	0.261
PHCU B	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
Degree Centrality	0.43	0.40	0.43	0.45	0.34	0.38	0.37	0.40	0.04
Out Degree	0.50	0.12	0.50	0.52	0.16	0.41	0.40	0.37	0.166
In Degree	0.41	0.48	0.18	0.34	0.39	0.18	0.13	0.30	0.138
Density	0.17	0.10	0.09	0.11	0.07	0.05	0.05	0.09	0.043
No. ties	94	56	49	61	36	25	28	49.86	23.8
Distance	2.4	2.3	2	2.3	2	1.7	1.7	2.06	0.288

PHCU	All networks (ALL)	All advice seeking networks (AS)	All advice giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All newborn care advice seeking or giving networks (Newborn)	descriptive statistics	
PHCU C	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
Degree Centrality	0.40	0.36	0.37	0.37	0.37	0.34	0.46	0.38	0.04
Out Degree	0.47	0.30	0.44	0.37	0.31	0.23	0.52	0.38	0.104
In Degree	0.35	0.36	0.26	0.31	0.43	0.23	0.23	0.31	0.078
Density	0.33	0.22	0.20	0.20	0.20	0.12	0.12	0.20	0.071
No. ties	113	74	68	69	69	41	41	67.86	24.22
Distance	1.8	1.8	2.4	2.3	2.3	1.9	2	2.07	0.256
PHCU D	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
Degree Centrality	0.40	0.42	0.36	0.50	0.25	0.27	0.20	0.34	0.107
Out Degree	0.35	0.13	0.39	0.24	0.15	0.30	0.17	0.25	0.103
In Degree	0.47	0.36	0.45	0.41	0.27	0.18	0.23	0.34	0.113
Density	0.16	0.10	0.13	0.11	0.08	0.05	0.06	0.10	0.041
No. ties	56	35	45	37	26	17	20	33.71	13.92
Distance	2	2.6	2.6	2.4	2.7	1.4	2	2.24	0.469
PHCU E	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
Degree Centrality	0.35	0.44	0.42	0.35	0.46	0.44	0.32	0.40	0.055

PHCU	All networks (ALL)	All advice seeking networks (AS)	All advice giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All newborn care advice seeking or giving networks (Newborn)	descriptive statistics	
PHCU E	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
Out Degree	0.39	0.25	0.64	0.24	0.27	0.53	0.50	0.40	0.157
In Degree	0.46	0.63	0.18	0.39	0.49	0.22	0.19	0.37	0.175
Density	0.50	0.27	0.26	0.28	0.25	0.22	0.25	0.29	0.092
No. ties	104	56	55	58	53	47	52	60.71	19.41
Distance	1.5	1.6	1.9	2.2	2.3	2.2	2.2	1.99	0.324
PHCU F	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
Degree Centrality	0.49	0.55	0.47	0.50	0.43	0.45	0.51	0.49	0.038
Out Degree	0.49	0.20	0.50	0.37	0.28	0.36	0.26	0.35	0.115
In Degree	0.58	0.63	0.20	0.45	0.45	0.40	0.43	0.45	0.139
Density	0.28	0.14	0.19	0.19	0.15	0.15	0.13	0.17	0.05
No. ties	166	85	111	113	88	92	77	104.57	30.17
Distance	1.8	2.4	2.2	1.9	2	2.4	2.4	2.16	0.257
PHCU G	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
Degree Centrality	0.52	0.50	0.47	0.37	0.51	0.20	0.26	0.40	0.13
Out Degree	0.43	0.25	0.53	0.34	0.47	0.16	0.23	0.34	0.138

PHCU	All networks (ALL)	All advice seeking networks (AS)	All advice giving networks (AG)	All ANC advice seeking or giving networks (ANC)	All Maternity advice seeking or giving networks (MAT)	All PNC advice seeking or giving networks (PNC)	All newborn care advice seeking or giving networks (Newborn)	descriptive statistics	
PHCU G	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
In Degree	0.43	0.45	0.13	0.27	0.27	0.09	0.23	0.27	0.135
Density	0.22	0.14	0.13	0.12	0.12	0.04	0.10	0.12	0.054
No. ties	60	39	35	33	33	11	26	33.86	14.7
Distance	2	2.1	2.2	2.1	2	1.4	1.9	1.96	0.264
PHCU H	ALL	AS	AG	ANC	Maternity	PNC	Newborn	mean	standard deviation
Degree Centrality	0.57	0.38	0.54	0.47	0.45	0.27	0.26	0.42	0.123
Out Degree	0.53	0.26	0.60	0.33	0.36	0.26	0.23	0.37	0.143
In Degree	0.35	0.45	0.19	0.29	0.36	0.07	0.10	0.26	0.141
Density	0.18	0.09	0.12	0.11	0.09	0.06	0.04	0.10	0.047
No. ties	101	52	68	63	52	33	21	55.71	25.83
Distance	2	1.7	2.1	2.2	2.1	2.6	2	2.10	0.271

Additional File 4 Cadre with the highest in degree centrality value by network

Cadre	ANC	Maternity	PNC	Newborn	Total
Health Officer	1	1	2	1	5
Midwife	5	6	5	4	20
Nurse	2	1	2	4	9
Health Extension Worker	0	0	2	1	3